An overview of non-nickeliferous weathering crusts in Eastern Cuba

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Abstract

This paper presents an overview of the studies in non-nickeliferous weathering crusts initiated more than six decades ago in Eastern Cuba. This overview is based on a detailed literature review and a descriptive-critical discussion on these studies with the main objective of highlighting their achievements and failures. These investigations were motivated by the existence of large mineral deposits associated with different types of weathering crusts in this region and were mainly focused on finding bauxites. However, prospects could not be delineated because the alumina contents in these geological objects were below those required to classify them as bauxites. This limited the evaluation of the possibilities of assimilating these crusts in such industries as the ceramic, construction and refractory, among others, which can contribute significantly to the sustainable local development. Generally, in all these investigations there is an absence of solid mineralogical and geochemical criteria for the characterization and classification of different aluminium-rich weathering crusts. The SiO_2-Al_2O_3-Fe_2O_3 contents in the region show that most of the weathering crusts as ferrosialitic. There are possibilities of finding sialitic, ferrallitic and allitic types in Cayo Guam, Centeno, Quesigua, Puriales de Caujerí, Quemado del Negro and Cantarrana. In overview, the level of study of the non-nickeliferous weathering crusts widely developed on gabbros, volcanic, metamorphic and sedimentary rocks in Eastern Cuba is relatively low. Further investigations including detailed profile sampling, chemical and mineralogical analyses in Téneme, Centeno, Cayo Guam, Quemado del Negro and Cantarrana are proposed which, in our opinion, are perspectives for allitic deposits.

Key words

Alumina, Eastern Cuba, geochemistry, mineralogy, Non-nickeliferous weathering crusts.

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Un acercamiento a las cortezas de meteorización no niquelíferas del nordeste de Cuba

Resumen

Este artículo expone el resultado de la revisión de los estudios sobre cortezas de meteorización no niquelíferas realizados en Cuba Oriental a partir de 1943, los cuales estuvieron dirigidos a la búsqueda de bauxitas, motivados por la existencia en la región de grandes depósitos minerales asociados a diferentes tipos de cortezas de meteorización. Los bajos contenidos de alúmina reportados no permitieron delimitar cortezas perspectivas para la explotación de bauxitas, lo que limitó la evaluación de las posibilidades de asimilar estas cortezas en industrias nacionales como la cerámica, materiales de construcción y refractaria, entre otras. Como elemento común de estos estudios vale señalar la ausencia, casi general, de criterios mineralógicos-geoquímicos sólidos para la caracterización y clasificación de las distintas cortezas de meteorización enriquecidas en alúmina. Los contenidos de SiO_2-Al_2O_3-Fe_2O_3 en la región apuntan a que la mayoría de las cortezas de meteorización son ferrosialíticas. Cortezas sialíticas, silícicas, ferralíticas y alíticas pueden encontrarse en Cayo Guam, Centeno, Quesigua, Puriales de Caujerí, Quemado del Negro y Cantarrana. El grado de estudio de las cortezas de meteorización no niquelíferas sobre gabros, rocas volcánicas, metamórficas y sedimentarias, en Cuba Oriental es relativamente bajo. Se proponen realizar investigaciones detalladas en Téneme, Centeno, Cayo Guam, Quemado del Negro y Cantarrana con perspectivas para alitas.

Palabras clave

Alúmina, Cuba Oriental, geoquímica, mineralogía, Cortezas de meteorización no niquelíferas.

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INTRODUCTION

The existence of large deposits associated with different types of weathering crusts in Cuba, the discovery of bauxites as the principal aluminium ore in the previous century, together with the discovery of large bauxite deposits in Jamaica, motivated the search for bauxites in Cuba (Lavandero *et al*. 2009). However, no lateritic bauxite deposits were found. In consequence, the failure to find large economic bauxite deposits masked the evaluation of other weathering products rich in aluminium which may have other important industrial uses.

The only industrial use the non-nickeliferous weathering crust resources have in Eastern Cuba is raw materials for a small roofing tiles factory in Centeno, close to Moa, Holguín province, in north-Eastern Cuba. This small scale industrial benefit is a direct result of the limited geological evaluation of the weathering products rich in aluminium which may be used in ceramic, refractory and construction industries.

The Industrial Mineral Deposits and Occurrences Map of the Republic of Cuba (Coutin *et al*. 1988) which at present is the official reference document in Cuba, offers a genetic and industrial uses classification (Castellanos-Rosales 1992). However, this classification does not specify in each industrial group the raw material type for each specific industrial use, and furthermore, some mineral occurrences are not clearly reflected in this map.

There are other classifications of weathering crusts and associated mineral resources (Tardy *et al.* 1993). Most of the classifications presented in the current investigations do not permit a grouping of the uses of the evaluated resources. However, due to the fact that the different classifications used in these studies are important from different geological points of view, they merit consideration as reference for further review, modifications and development of other classification schemes.

The main objective of this work is to present an overview of the current studies on the non-nickeliferous weathering crusts in Eastern Cuba based on an extensive literature review and summarized in a descriptive as well as critical discussion of these investigations carried out for more than six decades, highlighting their achievements and limitations. Further investigations including detailed profile sampling, chemical and mineralogical analyses in Téneme, Centeno, Cayo Guam, Quemado del Negro and Cantarrana are proposed as perspectives for allitic as well as other aluminium- rich deposits.

MATERIALS AND METHODS

Chemical and mineralogical composition data of the weathering crusts were obtained from an extensive review of the investigations carried out between 1943 and 2009 focused on the non-nickeliferous weathering crusts developed on different types of rock in the north-Eastern part of Cuba. Over 20 reports from the Mineral Resources National Office (ONRM-abbreviated in Spanish), a large number of scientific publications in national and internationals journals, technical and scientific events, undergraduate, master's and doctoral theses were consulted.

Chemical composition data in most studies were obtained by X-Ray Fluorescence at the *Empresa Ernesto Guevara*, *Geominera Oriente* and other laboratories in Cuba using different spectrometers. Chemical composition analyses for Baconal, El Culebro, Caimanes and Farallones areas were carried out at the University of Barcelona (UB), Spain, using a Panalytical (Philips) PW2400 spectrometer with an Rh X-ray tube operated at 60 KeV, 125 mA and 3 000 W.

Underlying rock types were obtained from the Geological Map of Cuba published in 2001 by the Institute of Geology and Palaeontology (IGP) in digital format. These include gabbros of ophiolitic affinity, Cretaceous and Palaeogene Island Arc volcanics, volcano-sedimentary of the Sabaneta Formation, metamorphic rocks of the La Farola Formations, volcano-sedimentary-carbonated sequences, carbonated and sedimentary rocks of the Gran Tierra, Yateras and Maquey Formations respectively and metamorphic rocks of the Sierra Verde Formation.

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Essential chemical composition and bedrock data from each work were summarized and a descriptive-critical synthesis was drafted, analyzing at detail the scientific and practical contributions and insufficiencies. This synthesis constitutes the present overview on the actual developments in the studies of the different non-nickeliferous weathering crusts in Eastern Cuba.

INVESTIGATIONS ON NON-NICKELIFEROUS WEATHERING CRUSTS IN EASTERN CUBA

Intensive investigations in search of bauxites were carried out by the United States Geological Survey between 1943 and 1948 but regional investigations did not ascertain the presence of such deposits. Brammlete (1943), one of the principal researchers, acknowledged that these investigations did not have the necessary scientific vigour and were restricted only to surface details. In conclusion, it was indicated that large Jamaican-type bauxite deposits could not be found in Cuba. However, the possibilities of finding smaller deposits that could eventually be exploited economically were not evaluated.

After the Cuba-Hungarian geological group published the Geological Map of the former Eastern Province of Cuba between 1972 and 1976, many researchers have worked in the non-nickeliferous weathering crusts with the objective of finding and evaluating bauxites. This led to discovery of karstic bauxites in areas around Guantánamo (De Dios & Cueto 1982).

Buguelskey & Formell (1974) indicated the existence of *in situ* and re-deposited aluminous weathering crusts in Cuba. The results produced by these researchers are of unquestionable practical value and served as reference in bauxites explorations in the region. However, no mention was made in these researches of any other use that may be attributed to those weathered materials that did not contain the required minimum alumina contents in order to be classified as bauxites *sensu strictus.*

Nagy (1976, 1983) carried out outstanding works in which the initial compositional results of *in situ* and re-deposited weathering crusts

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were offered. Formell *et al.* (1977) stated that in the northeast and east of the Central-Eastern Provinces there are potential weathering crusts developed on rocks of different compositions. These authors proposed detailed studies which include systematic sampling and low-depth drillings in the carbonated plateaus to the North and East of Guantánamo.

Dudich (1975) carried out chemical analysis on several principal components of materials that compose the kaolinite-ochre weathering profile of the gabbros in the Cantarrana region. Besides the fact that sampling was not done systematically, the results showed average Al_2O_3 and SiO_2 contents of about 33% and 37% respectively, with an average aluminium modulus of 0,89. This affirms the opinion that the weathering crust developed on gabbros in this area have a kaolinitic-ochre composition, but this does not invalidate the possibilities of finding bauxitic occurrences in the whole area where weathering crusts are developed on gabbros. Systematic investigations are recommended in the areas where weathering crusts develop on gabbros in Cantarrana, Quesigua and Rio Jiguaní.

Guerasimov *et al*. (1976) evaluated the composition of the formations that contain bauxites in Cuba and their perspectives for alumina. They carried out sampling in Eastern Cuba and delineated Cantarrana as prospective for bauxites. Seven of the samples from Cantarrana showed chemical compositions similar to high grade bauxites. However, their bauxitic composition is due to the fact that the analyses were done for the bauxites. Optic microscopy and X-Ray diffraction studies of these samples indicated a gibbsite-goethite mineralogical composition. 2 samples contained fragments of gabbros. 3 samples represented what they called “tiger” type structural bauxites and 1 sample represented a transition of bauxitic clay to “tiger” type. These authors concluded that the weathering crusts in Cantarrana were developed on gabbros and are essentially clayey, probably kaolinitic, with the presence of gibbsite. Also, they concluded that the *in situ* weathering crusts in Quesigua-Jiguaní-Yamanigüey (a perspective area limited by faults) and re-deposited

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weathering crusts in the areas around are direct indications of these genetic types established in Cuba.

In consequence, the findings of Guerasimov *et al*. (1976) did not imply the discovery of a bauxite deposit but it is of great importance in that it compensates undoubtedly the presence of structural bauxites developed on gabbros. They recommended a systematic investigation of the sub-lateritic weathering crust developed on gabbros in search of well developed “tiger” type profiles. The sub-lateritic weathering crust has thicknesses of up to 20-30 m. Guerasimov's works opened a new fact-finding line on the non-nickeliferous weathering crusts developed on gabbroic rocks. However, those that are developed on volcanic rocks are frequently mistaken with those on gabbros given their extensive spatial relation to nickel laterites and due to the lack of qualitative interpretation of geochemical data and detailed representation.

Elmer (1977) carried out a geological reconnaissance work on bauxites and attempted to elaborate the principles of bauxite prognosis in Cuba. He concluded in his survey that in Cantarrana and areas around Sierra de Moa allitization processes continue but there is no evidence of the existence of considerable quantities of high grade bauxites. These occurrences are close to the lower limit of the favourable latitude over which economically important bauxitization occur.

Of great importance was the work realized by Dudich (1978), who extensively reviewed concretely all the known allites occurrences in Cuba, offering useful recommendations for the application of a selective method in the geological exploration of bauxites in the whole Cuban territory. No industrial classifications and uses were proposed or recommended.

Buguelskey (1979) concluded in his investigations that the Eastern region of Cuba represents an exceptional region for bauxites prospection due to the extensive development of weathering crusts.

The above-mentioned authors recommend that during the evaluation of the stated areas attention should be drown to the residual weathering crusts as well as the re-deposited friable deposits in the peripheral areas of the gabbros massif. Also, the kaolinitic clays that constitute a significant part of the weathering crusts developed on gabbroid and in turn are a very necessary raw material should be taken into consideration in these evaluations.

Studies in Cantarrana and Quemado del Negro continued in 1980. Lateritization in these areas is a product of weathering of gabbros which gave rise to a sialitic profile. These studies indicated that the possibilities of aluminium hydroxide enrichment in the weathering crusts due to selective leaching of silica are limited.

Other rock types appear in Quemado del Negro, Cantarrana and Yamanigüey with a fine-grained texture and a grey to greyish-blue colour. According to Ramayo (2003), there are volcanic rocks in these areas. In our opinion, sampling and chemical composition analyses should be carried out on bedrock and weathered product in order to establish the parent rock-weathering crust patterns thus providing geochemical evidence to support these comments.

Coutin *et al*. (1983) proposed 14 perspective bauxite zones using surface evidence and stated that the same geomorphologic and climatic conditions prevailed during the Neocene-Quaternary and still exist around Guantánamo. They recommended geological exploration in the entire region with drillings down to the bottom of the depressions.

A more complete work on bauxites in Cuba was carried out by Ponce *et al*. (1985) entitled “Perspective Evaluation of Bauxites” in which an evaluation of the bauxite perspectives in the national territory was made. This work is important to geologists dedicated to similar investigations in the territory.

Korpas (1988) based his work on the investigation carried out by Ponce *et al*. (1985) and published the “Methodological Geological

Principles of Bauxites Prognosis in Tropical Oceanic Island Arc areas in the example of Cuba." Also, basing on literature review, the referred author elaborated two variations of bauxitic models which refer to the genetic type of karstic bauxites. The karstic processes manifest to a great extent in the national territory where terrigeneous and carbonated deposits are developed. Numerous allitic and karstic bauxite occurrences are associated with the karstic relief in almost all the national provinces. However, these models have not been used in any evaluation of karstic bauxites occurrences in Cuba.

Orozco (1995) selected a well exposed outcrop in Cayo Guam, concluding that at the base of the profile there are highly weathered gabbros, altered to a white-coloured material and with an earthy-clayey feel and high plasticity. Towards the upper part of the profile there is a gradual transition of material similar to those of the profile base, forming a weathering crust of colours which vary from yellowish-brown to dark red up-profile, indicating an increment in iron content.

Pons & Leyva (1996) determined the chemical composition of ferro-kaolinitc- gibbsitic clay deposits in Centeno with the objective of characterizing their application as refractory material in the Nickel Mechanical Company (EMNi-abbreviations in Spanish), concluding that these deposits are a result of the weathering of ophiolitic gabbros and can be used as refractory material.

According to Orozco (1995), Pons & Leyva (1996) the weathering crusts in Centeno and Cayo Guam are kaolinitic clays mainly related to gabbros of variable dimensions. However, geochemical evidences of weathering crusts developed on volcanic rocks in Centeno have been provided by Cámara (2007).

Fonseca (2004) carried out an investigation aimed at evaluation mixtures of clays in Centeno. After accomplishing all experimentation work and statistical analysis of the results that comprise his fundamental objectives, he concluded that the potential industrial utility of the large clay extensions in Centeno have not been adequately evaluated. The chemical composition and other physical properties of the Centeno clays are very similar to common red clays.

A number of undergraduate theses were elaborated in relation to the perspective evaluation of bauxites in different sectors of Holguín and Guantánamo Provinces between 1980 and 2007 (González & Barcaz, 1981, Cobas & Vargas 1982, De Dios & Cueto 1982, Moreno& Pérez, 1982, Pine & Rosales 1982). The methodology used in all these works consisted in literature review, fieldworks and chemical analyses of a few major elements, mainly Fe, Si, Al, Na, Ca and Mg. The objective was to find bauxites but the existence of bauxites *sensu strictus* was not confirmed. Consequently, evaluations of industrial perspectives of alumina-rich materials existent in this region were not realized. The interpretation of geochemical and mineralogical data was not done adequately.

Garcia (1985) made a systematization and generalization of existent geological-technological information on industrial minerals as raw materials for construction in the Holguín province. He made a description of the raw materials taking into account their location in terms of structural units, lithologic complexes and host formations, as well as a genetic-industrial classification. He also presented a general evaluation of the perspective area and the potential of industrial minerals in the province.

Betancourt (1992) made a scientific and technical review of red ceramics and their application in the construction industry in Cuba as well as a preliminary study on the fundamental raw materials for ceramic products in Moa and Holguín province.

The conclusions by Garcia (1985) and Betancourt (1992) are similar. Both concluded that the potential of clays as raw materials for red ceramics and other products in Moa and the rest of Holguín Province have not been fully evaluated. They also affirmed that the genetic types of clays with more perspectives in this region are alluvial. Betancourt (1992) stated that the clays were formed from gabbros, although this affirmation is based on an unreliable chemical analysis on a few samples of the clays and without any parent rock-weathering crust correlation. They further concluded that the industrial clays considered in this region have a mixture of different minerals, are mouldable but show drying defects. They recommended the continuation of the studies on raw materials in different lithologies as well as detailed studies on the mineralogy of the clays using analytical techniques and technological assays.

Oliva (1992) geologically characterized the weathering crusts in Cantarrana and concluded that ores in these crusts depend on the bedrock from which the crusts are formed. He established that the petrochemical characteristics are a determinant geochemical factor in the type and characteristic of the ore deposits. Chemical analyses were done on the gabbros but not on the weathering crust developed on them.

Fadel (2005) determined the mineralogical properties of seven samples of clayey material from four horizons of the weathering crust developed on gabbros in Cayo Guam. Basing on X-Ray Diffraction analyses of the total samples and the grain size fractions, the referred author concluded that the principal mineral phases present are gibbsite, kaolinite and goethite, with the possible presence of smectites and illite groups.

Cámara (2007) analyzed the geochemistry of the non-nickeliferous weathering crusts in Centeno-Jucaral and Cayo Guam. He established that the crusts in the Centeno-Jucaral sector were formed from oceanic floor volcanic rocks, while those of Cayo Guam were originated from banded gabbros whose bands are rich in calcic plagioclase and magnesian olivine, found very close to Moho Transition Zone (MTZ). Furthermore, he established the existence of “well defined” bauxitic clays according to the existent international classifications. This classification was done taking into account the bauxitic nature of the crust, i.e., using the ALPHA coefficient. These onclusions were based on review of previous works on bedrock (Proenza *et al*. 1999, Marchesi 2006, Pereira-Ginga 2006) and partial major element geochemical data (Cámara 2007), which did not include rare earth and trace elements geochemical analyses and behaviour.

More recent geological studies in Moa recommend further investigations in non-nickeliferous weathering crusts given the potential industrial benefit of these resources to industries such as the construction, ceramics, mineral pigments, and other industries which require such raw materials.

Lavandero *et al*. (2009) evaluated the actual problems in bauxite and allites studies in Cuba based on a detailed literature review. They concluded that favourable geological conditions for the genesis of different kinds of aluminium-rich weathering crusts exist in Cuba. These may be exploited on a small scale, taking into account the beneficiary methods which process low grade bauxites together with the extraction of other minerals. They recommended the future prospection in the areas with high possibilities in the entire Cuban territory.

RESULTS AND DISCUSSION

The SiO_2-Al_2O_3-Fe_2O_3 plot in Figure 1 shows that the majority of the known mineral occurrences and deposits in Eastern Cuba are ferrosialitic, in accordance to the chemical analyses data of Si, Al and Fe oxides content from the investigations on the non-nickeliferous weathering crusts referred to in this work. It is possible to find sialitic weathering crusts in Cayo Guam, Centeno, Cantarrana, Sierra Verde and Puriales de Caujerí-Viento Frio (Pons *et al*. 1997, Orozco 1995, Laverov 1985, Cobas & Vargas 1982, Guerasimov *et al*. 1976). In Quemado del Negro and Cantarrana the weathering crusts have more than 60 wt % of alumina (González & Barcaz 1981, Guerasimov *et al*.1976). Iron contents are in the range of 2 to 40 wt % in the greater part of the study area, while silica contents are within the range of 3 to 75 wt %, as in the case of Quemado del Negro and Cantarrana (González & Barcaz 1981, Guerasimov 1976). These weathering crusts are mainly ferrallitic. Allitic weathering crusts may be present in Quemado del Negro and Cantarrana, however, this can be ascertained by extended sampling and precise chemical analyses.

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It is worthy of note that the only recent data used in the SiO_2-Al_2O_3-Fe_2O_3 plot were taken from Njila & Díaz-Martínez (2009), Cámara (2007) and Fadel (2005). The reliability of all the other chemical data is minimal and further chemical analyses using precise, recent equipment and standard techniques should be able to provide more reliable data.

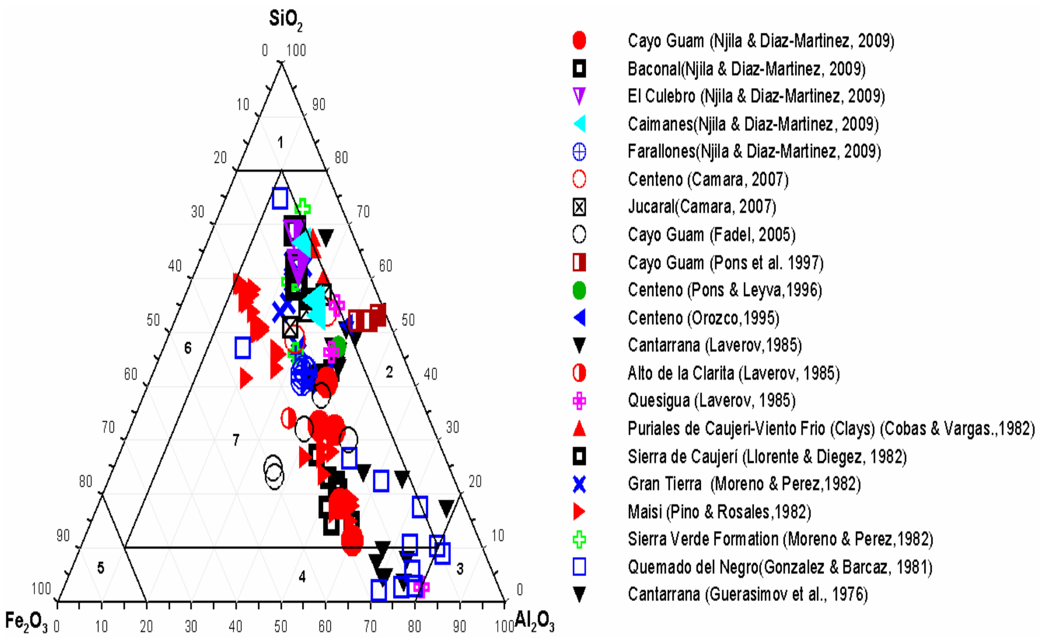

Figure 1. SiO_2-Al_2O_3-Fe_2O_3 plot for the non-nickeliferous weathering crust in Eastern Cuba. 1- silicic; 2- sialitic; 3- allitic; 4- ferrallitic; 5- ferric; 6- ferrisilicic; 7- ferrosialitic.

North-Eastern Holguín Province

In Eastern Cuba there are favourable climatic, tectonic, geological, lithologic and geomorphologic conditions for the formation of large accumulations of different weathering crusts. Detailed geological studies which include geochemical and mineralogical analyses should be carried out in the entire region to evaluate the potential benefit of the industrial rock and mineral resources in the non-nickeliferous weathering crusts developed on volcanic, volcano-sedimentary and basic rocks of ophiolitic affinity. Probabilities of discovering aluminium-rich deposits and occurrences can be inferred from geochemical and mineralogical analogy in similar weathering crusts with appreciable alumina contents in similar environments.

The current studies on the non-nickeliferous weathering crusts in Eastern Cuba are limited to major element chemical analyses by XRF, phase analyses by XRD, area reconnaissance and surface sampling. The major elements analyzed on average include Si, Al, Fe, Ca, Mg, Na and K. The interpretation of geochemical and mineralogical data is inclined towards the final products of one given process without taking into account the importance of all the material present, as in the works of González & Barcaz 1981, Cobas & Vargas 1982, De Dios & Cueto 1982, Moreno & Pérez 1982 and Pino & Rosales 1982. Important aspects of regional geology, geodynamic environment of formation, bedrock lithologies, geochemical behaviour of trace elements during formation, profile types, geochemical and mineralogical zoning were not considered in these studies.

As evidenced from the current studies, it has not been possible to find large deposits and this apparently minimizes the importance of elaborating an Industrial Rock and Mineral Deposits and Occurrences Map of the weathering crusts in Eastern Cuba. However, this map may be valuable in facilitating a visible graphical appreciation of the zones and areas where the investigations have been carried out, creating a base for the perfection of future investigations and modifications on existent maps.

Figure 2 shows the distribution of the non-nickeliferous weathering crust in Eastern Cuba according to bedrock. These crusts are largely distributed over gabbros, metamorphic schist, volcanic and sedimentary rocks (Njila & Díaz-Martínez 2009). However, their spatial representation is not clear and some weathering crusts developed on gabbros, volcanic rocks and volcano-sedimentary rocks in Eastern Cuba (proposed in this paper, Table 1) do not appear or are not properly represented in the 1:100000 Geological Map of Cuba (Cuba-Hungary Brigade 2001).

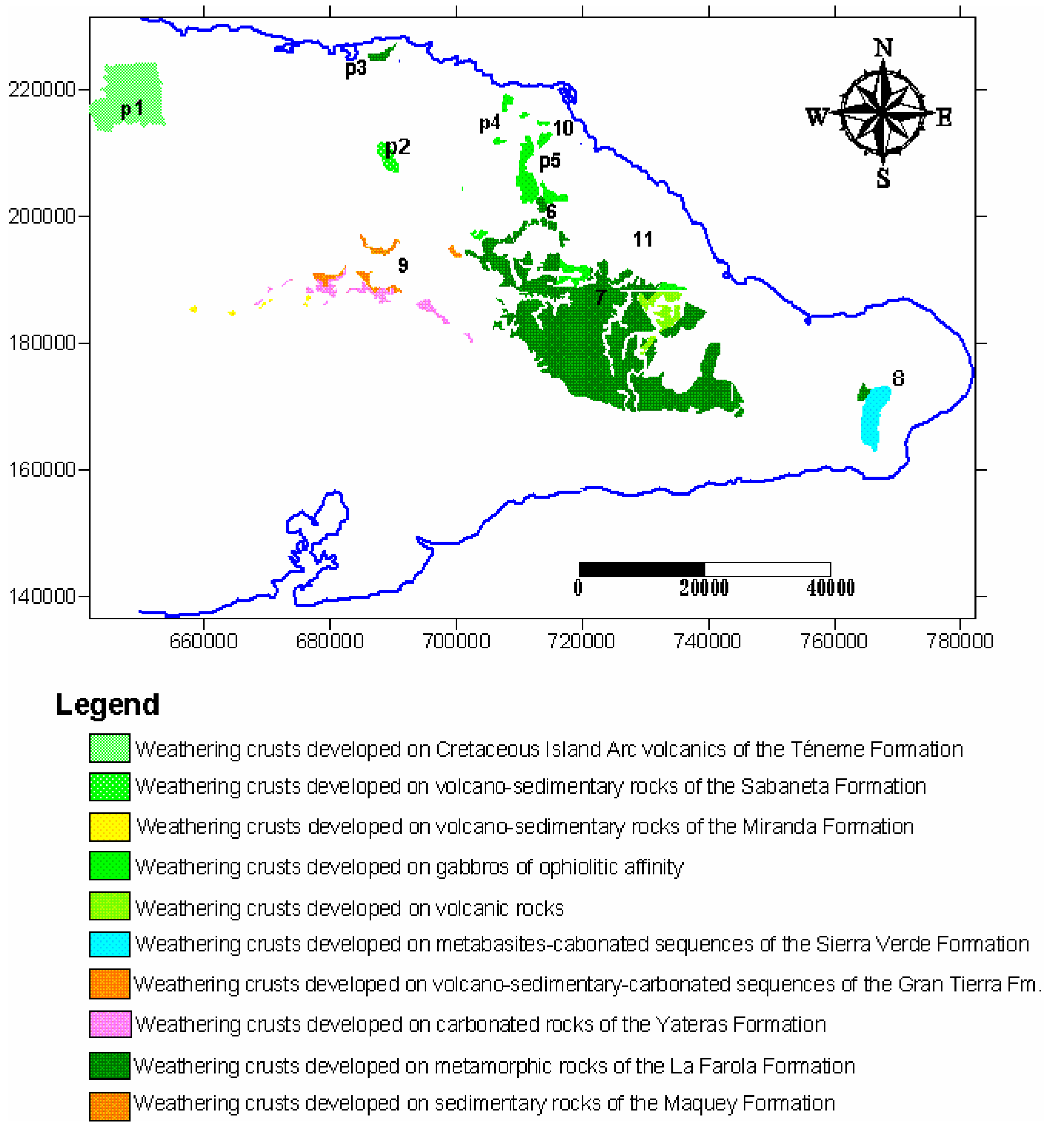

Figure 2. Distribution of the non-nickeliferous weathering crust in Eastern Cuba according to bedrock. *p1-Baconal, El Culebro; p2-Caimanes, Farallones; p3-Centeno-Jucaral; p4-Cayo Guam; p5-Quemado del Negro, Cantarrana; 6-Rio Jiguaní; 7-Puriales, Sierra de Caujerí-Viento Frío; 8-Sierra Verde Formation, Maisí; 9-Gran Tierra; 10-Quesigua; 11-Alto de la Clarita.*

Proposed areas in Eastern Cuba

Téneme sector (Baconal and El Culebro)

The non-nickeliferous weathering crusts in Baconal and El Culebro extend over the whole south flank of the area where volcanic rocks development in the Téneme Formation. These crusts are residual, *in situ* and originated from the weathering of basalts and basaltic andesites. Further south they are in contact with nickeliferous laterites developed on serpentines (Njila & Díaz-Martínez 2009).

In Baconal and El Culebro there are *in situ* weathering crusts with thickness of more than 10 meters (Njila & Díaz-Martínez 2009). There is a small brick industry in the El Culebro sector.

Farallones de Moa sector

Non-nickeliferous weathering crusts are developed on zeolitic green tuffs of the Sabaneta Formation (Palaeocene–Middle Eocene) in the Caimanes zone. Farallones is located to the east of Caimanes, where brown tuffs intercalated with zeolitic green tuffs appear and are dominant in the region (Sánchez 2005).

Centeno-Jucaral sector

The non-nickeliferous weathering crusts of the sector Centeno-Jucaral are developed on volcanic rocks (pillow lavas) of ophiolitic affinity (Cámara 2007). There is a small tile production in Centeno.

Cayo Guam sector

The gabbros in Cayo Guam are highly weathered and form non-nickeliferous weathering crusts rich in kaolinitic clays, iron oxides and hydroxides. Towards the northeast part there are Cretaceous volcanic rocks. All these lithologies are extremely weathered and can only be freshly observed in the upper part of the basin and along the Cayo Guam River banks (Orozco 1995, Pons & Leyva 1996).

Quemado del Negro and Cantarrana

There are gibbsitic bauxite occurrences in these sectors. The weathering crusts developed on gabbros and plagioperidotites have thicknesses of 0.5 to 3.0 metres and are of great interest in bauxite exploration (Rodríguez *et al*. 1985).

The relief in the Cantarrana zone is an oval plateau surface, with a height of 300 m above sea level. Apparently the major development of the crust is found towards the laterals where there is vegetation cover and where the hydrographical network is poor (De Dios & Cueto 1982). Table 1 shows genetic types, bedrock, average chemical and mineralogical composition of the known and proposed occurrences in the north-Eastern Holguín province.

Table 1. Known deposits and proposed occurrences in the north-Eastern Holguín province. (*Proposed sectors, Kaol. =Kaolinite, Gibb. =Gibbsite, goet. =Goethite, hem. =Hematite. OIA=Oceanic Island Arc. Volc.-sed. =volcano-sedimentary)

Sector	Bedrock; affinity	Genetic Types	Mineralogical Composition (crust)	Chemical Composition (wt %)			Reference
				Al_2O_3	SiO_2	Fe_2O_3	
Centeno	Volcanic; Ophiolitic	Residual	Kaol, Gibb;	26,99	36,85	11,72	Cámara 2007
*Jucaral	Volcanic; Ophiolitic	Residual	Kaol, Gibb	22,18	41,72	13,36	
Cayo Guam	Gabbros; Ophiolitic	Residual	Gibb, Kaol, Goet	28,15	42,19	7,03	Orozco 1995
Quemado del Negro	Gabbros, Volcanic; Ophiolitic	Residual	Kaol, Gibb, Goet	51,41	4,78	18,71	González 1981
Cantarrana	Gabbros; Ophiolitic	Residual	Gibb	32,44	37,49	11,74	Guerasimov *et al.* 1976
*Téneme	Volcanic; OIA	Residual	Kaol, Gibb;	19.33	56.25	13.23	Njila & Díaz-Martínez 2009
*Farallones de Moa	Volc.-sed.; OIA	Residual	Kaol, Hem;	25.40	41.77	15.55	Njila & Díaz-Martínez 2009

CONCLUSIONS

The studies in the non-nickeliferous weathering crusts indicate that these crusts are widely developed on gabbros, volcanic, volcano-sedimentary, metamorphic and sedimentary rocks and largely distributed in Eastern Cuba. The geochemical and mineralogical aspects have not been adequately characterized given that only information from the chemical and mineralogical analyses of major elements and principal mineral phases is available. The failure to find large bauxite deposits in Eastern Cuba minimized the evaluation of the potential industrial uses of the aluminium-rich weathering crusts which have only been evaluated in a few sectors of the Holguín province. Cayo Guam, Centeno, Quesigua, Puriales de Caujerí, Quemado del Negro and Cantarrana areas are perspectives for sialitic, silicic, ferrallitic and allitic deposits.

The classification of non-nickeliferous weathering crusts in relation to chemical and mineralogical composition is not presented the current investigations. The Industrial Mineral Deposits and Occurrences Map of the Republic of Cuba (Coutin *et al*. 1988) offer a genetic and industrial uses classification which does not specify in each industrial group the raw material type.

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