AeroGammaspectrometry for Lode-Au Deposits Exploration In Western Pampean Ranges-Argentine

Fanton, Gerardo[1], Martinez, M.Patricia[1,2], Gimenez, Mario E[1,2]. 1-IGSFV-UNSJ, 2-CONICET
Instituto Geofisico Sismológico Volponi- UNSJ- Adress: Ruta 12 – km 17-Jardín de los Poetas-C.P. 5407 – Marquesado-San Juan – Argentina. E-mail: gfanton@unsj-cuim.edu.ar

This paper was prepared for presentation during the 12th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, August 15-18, 2011.

Given the importance and economic potential of the region was held data processing geophysics obtained gammaspectrometrics maps relationship Th / K, Kd (potassium anomalous) and parameter F. Finally a ternary map data gammaspectrometrics where anomalous potassium integrate data, parameter F and K / Th. From the interpretation of these maps could define hydrothermal alteration zones associated with the presence of gold mineralization.

Introduction

Mineral exploration in regions that experienced hydrothermal processes, mainly those controlled by shear zones, has received a large attention all over the world. Percolating solutions may be composed of water, silica, sulphide and chlorine compounds, carbonates, and K, Na, Ca, Fe, and Mg. Precious metals can precipitate especially with sulphides in favorable structural sites forming ore deposits.

K40 is associated with K during hydrothermal processes, being, therefore, an important component of these fluids. This isotope is responsible for most gamma radiation emitted by primary radioactive isotopes of the Earth's crust. In this way, airborne geophysics works well for mineral exploration because it can be applied in geological and structural mapping and can distinguish the most important hydrothermal zones related to ore deposits.

Several procedures have been proposed to minimize or eliminate the effects lithology, as well as the environment (Saunders et al., 1987; Saunders et al., 1994, Saunders et al, 1993; Gilbraith and Saunders, 1983), but most these studies were applied in oil exploration. Many years ago, Pires (1995) modified a method originally proposed by Saunders et al. (1987) for the identification of hydrothermal areas in Brazil.

The quartz vein systems which store and a minority Au mineralization of Cu and Ag occur widely across the Sierras de Las Minas, Ulapes and Chepes (Cravero et al., 1988; Ríos Gómez et al., 1992, JICA-MMAJ, 1993). The deposits were worked initially to late 19, and small-scale mining has continued to the present. Most deposits are hosted in granites and calc-alkaline granodiorites type I Chepes Igneous Complex, which were emplaced, metamorphosed in amphibolites facies, and deformed in the Late Ordovician (Pieters et al., 1997, Pankhurst et al ., 1996 and 1998).

Multiple occurrences of Au + /-Cu + /-Ag in the Sierra de Chepes are hosted by metasedimentary rocks and psammitic pelitic rocks (volcanic?) Metamorphic Complex metamorphosed feldspathic Olta early Cambrian. The biggest areas of stress up to several kilometers wide was developed during the deformation produced in the late Ordovician and partly controlled the emplacement of leucogranite Chepes Igneous Complex. Many of the high-stress areas have north-south trending aeromagnetic and show very low response, and develop mesh biotite-muscovite shear associated with steep reverse movement (Pieters et al., 1997).

This work helps to evaluate the use of aerial gamma ray data processing procedures to map and help in identifying most feasible hydrothermal zone for gold deposits. The traditional processing methods were applied in a defined geological area with a well known lode-Au deposit, and a large number of occurrences. Here we have applied an improved method of processing and data integration techniques to define the various grades of mineral deposits feasibility of either gold or base metal that was developed by Quadros (2003).

The methods of gamma-ray spectrometry play an important role in the exploration of gold mineral deposits associated with hydrothermal alteration. To Fornazzari et al. (2001), gamma-ray spectrometry either air or land in identification of hydrothermally altered areas and exploration of its relationship with mineralization of gold and silver, as well as base metals (Cu-Pb-Zn) in various geological environments.

Regional geology and deposit Au + / - Cu of the Sierra de Chepes and Las Minas

The Sierra de Los Llanos, Chepes and Ulapes-Las Minas, located in NW Argentina are part of the Precordillera geological province (Fig. 1). This whole ranges a series of blocks of crystalline basement rocks intruded by various rocks Paleozoic which were exposed as a result of Andean compressional tectonics developed from the

Miocene to the present. The ranges are bounded by scarpments developed on moderate to steeply dipping normal and reverse faults during the Cainozoic Andean uplift (Jordan and Allmendinger, 1986).

The Paleozoic basement of the Pampean ranges Chepes and Ulapes contains a number of domains of different lithology and structures, which are crossed by shear zones. (Pieters et al., 1997).

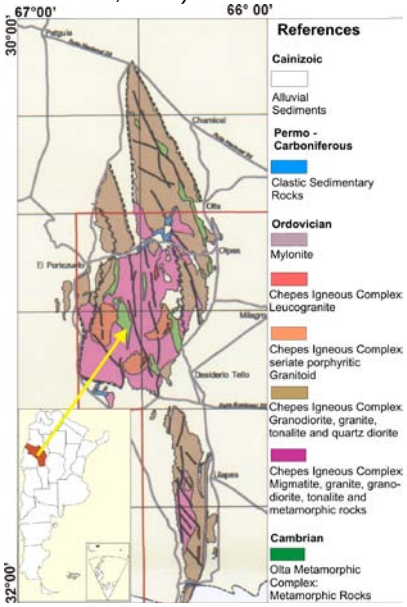

Fig.1. Location Map and Regional Geology (Taken from Pieters et al., 1997 and modified).

The area has two main structural domains: 1) Early Cambrian Pampean domain and 2) the domain Famatinian of the early Ordovician. These domains are juxtaposed in a complex way (Pieters et al., 1997).
In the map area the Cambrian metasediments and meta-igneous rocks of the basement are grouped together in the Olta Metamorphic Complex, and belong to the Pampean domain. These metamorphic rocks are intruded by early Ordovician granitoid and minor mafic bodies of the Chepes Igneous Complex, and at the same time were subjected to high-temperature/low pressure metamorphism and anatexis. The intrusives and migmatite make up the Famatinian domain which was formed during a phase of westward subduction beneath the Pampean terrane. Both domains were subjected to compressive non-coaxial deformation and retrogressive metamorphism in the late Ordovician. Subsequently, the domains were intruded by Devonian granites (not exposed but interpreted from airborne magnetics), and covered by Carboniferous and Permian continental sediments and Cainozoic continental sediments (Pieters et al., 1997).

The mineralization in veins rich in Au and Cu in the Sierra of Chepes, Ulapes and Las Minas are related to the intrusion of granites, a process that was important in the mobilization of metals (Cravero, 1999).

The latter author determined based on the morphology of the deposits, hydrothermal alteration, isotopic and fluid inclusion studies of the origin of gold deposits is mesothermal. Au–Cu–Ag-bearing quartz vein systems exhibit two principal orientations: NW- and NE striking; a few strike roughly E–W. The Devonian Au deposits are localised in transcurrent and reverse fault and shear zones that may be related to collision of the Chilenia terrane with the western margin of Gondwana during the newly defined Achalian orogeny. These deposits are considered to be members of the mesothermal lode Au family of systems found worldwide. (Skirrow et al., 2000).

Data

The data used in this study were collected for scientific cooperation project between AGSO and SEGEMAR during 1995-1996. We had access to them through the transfer of data by the SEGEMAR to IFIR -UNR. The data come from a program of high-resolution airborne geophysics. The aerial survey of gamma-ray spectrometry was carried out by World Geoscience in 1995 under the supervision of the Australian Geological Survey (AGSO). The lifting of aerial spectrometric data had the following characteristics: flight lines east-west by 500 m spacing between them and control lines north-south spacing each 5000m. The flight altitude was about 120 m above the ground; the sampling interval along the lines of flight is 0.1 seconds (7.3 meters) to position the aircraft during flight used a GPS system in differential mode one reading per second. The gamma ray spectrometer used was 256 channels of crystal volume NaI: 32lts, minimum volume of glass facing up: 8 liters, 0.1 seconds sampling interval. (Chambers, P, 1996).

Data Processing and Interpretation

Epigenetic mineralization processes, such as metamorphism, hydrothermal alteration, and weathering, can evidently modify the original concentration of radioelements. The hydrothermal solutions may be enriched in elements such as K+. A revision gold exploration (Hoover and Pierce, 1990) suggested K+ as the best element to locate ore deposits. In some situations, K+ enrichment is accompained by a depletion of Th, mainly in intense hydrothermal alteration. The concentration of K40 is related to the total concentration of K in rocks and hydrothermal solutions.

The concentration of K^{40} can be retrieved directly from the gamma radiation. However, U and Th measured by gamma radiation of Bi^{214} and Tl^{238} respectively. These radio-elements are generally concentrated in the residual liquid magma crystallization processes, therefore, can be incorporated in the final state of magmatic differentiation (Adams and Gasparini, 1970) and may be related to the formation of mineral deposits.

Although exploration gamma-ray spectrometry is based on physical parameters, their data can be converted into a geochemical measure the concentration of radioactive elements in the top of the soil and rocks (usually the first 30 cm, Dickson and Scott, 1997).

However, the main problem to discriminate reliable information from these data is related to geological

background effect, which influences the definition of hydrothermal áreas

Quadros et al. (2003) applied a method developed by Saunders et al. (1987), modified and used by Pires (1995).

We present here the application of these techniques in the Sierra de Chepes-Mines. Applies for the first time in Argentina, the method used by Quadros et al. (2003).

This method uses Th values as a lithologic control to define the ideal values of U and K. Saunders et al. (1987) and Pires (1995) claim that the lithology and environment influence the apparent concentrations of Th, U and K concentrations in a predictable way. Thus, it is argued that standardization of data by Th suppress the primary effects of all unwanted variables.

The use of Th as a normalizing also relates to the fact that it shows less mobility geochemistry (Adams and Gasparini, 1970). The methods of Saunders et al. (1987) and Pires (1995) are based on the following relationship:

Ki = (Kp/Thp) * Ths, (1)

Where:

Ki is the ideal potassium value, defined in relation to the concentration of Th
Kp is the K average map
Thp is the Th average map
Ths is the value of thorium for the measurement point.
Deviations (anomalies) of the actual values of the ideal values are obtained by the equation:

Kd = (K - Ki)/Ki, (2)

Where:

Kd represents the distribution and concentration of K anomalous result.
K is the potassium value corresponding to the point of measurement.
Ki is the ideal potassium value, defined in relation to the concentration of Th
The resulting value represent K distribution and concentration (map) resulting from hydrothermal processes.
Another method of data processing aerial gamma-ray spectrometry was proposed by Efimov (1978) and initially applied and Prichystal Gnojek (1985) to distinguish zinc mineralized area in Czechoslovakia. This method is generally known as the parameter F (Efimov, 1978). According to Efimov (1978) and Gnojek and Prichystal (1985), the parameter F describes two important relationships: (i) the abundance of K related to Th / U, and (ii) the abundance of U related to Th / K. These relationships can be expressed by the following equation:

F = K* (U/Th) = K* (Th/U) = U* (Th/K), (3)

The data of K, U, Th were grilled using the method of minimum curvature of the surface described by Briggs (1974) and Swain (1976). Since the grids of K, U, Th, performed the following processing operations:

A) Calculation of the relations U / K, U / Th and Th / K and generated their own maps. In this work, only shows the map Th / K, by its direct relationship with the mineralization (Fig. 2);
B) Calculation of the parameter F (Eq. 3), see Figure 3;
C) Calculation of Kd (Equation 2), see Fig 4.

All negative values generated by the correction, calibration, or by the equations, they withdrew after adding a constant.

The ratio Th / K (Fig. 2) was also discussed along with the results Kd. Low values of Th / K generally indicate hydrothermal processes, mainly in regions where K + is associated with hydrothermal processes, and does not depend on T. For example: Gnojek and Prichystal (1985) and Shives et al. (1997) refer to low values of the ratio Th / K as an indicator of hydrothermal alteration.

Both authors argue that there is a real antagonism between K and Th, which seems to be a characteristic feature of hydrothermal processes followed by an enrichment of K.

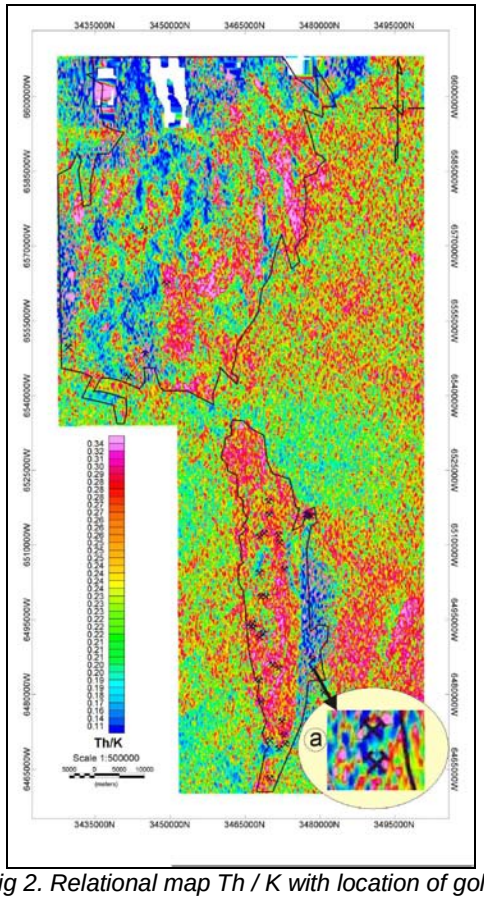

Fig 2. Relational map Th / K with location of gold deposits. In a) deposits in detail La Pirca y El Cerco.

Observation map Kd (Fig. 4) highlights some important points for mineral exploration in the region studied:

(A) Anomalous Kd areas or high Kd values, could be related vein gold deposits.
(B) There is a correlation between low values for the ratio Th / K (Fig. 2) and high values of Kd (Fig. 4).

The parameter F also uses the values of Th as an ideal lithologic control to set the values of U and K. The parameter F is to display a combined behavior of K and U in relation to hydrothermal processes, unless one of these two elements do not change their concentration during the process.

Observation of the F parameter map (Fig. 3) showed that the abnormal areas of the parameter F are closer to the reefs of Au occurrences known in the region studied.

We have integrated the information from the three maps (Th / K, Kd, and the parameter F) to highlight anomalous hydrothermal areas in the study region and define the feasibility of minerals. The integration of these data can be done in several ways (eg, An et al., 1991; Agterberg and Bonham-Carter, 1999; Quadros, 2000), but the easiest is to build a map ternary RGB (Red, Green, Blue, in English). However, for a better view, it is necessary that all the initial information is correlated in the same direction (positive anomalies are correlated).

Fig.3. Map location parameter F with gold deposits.

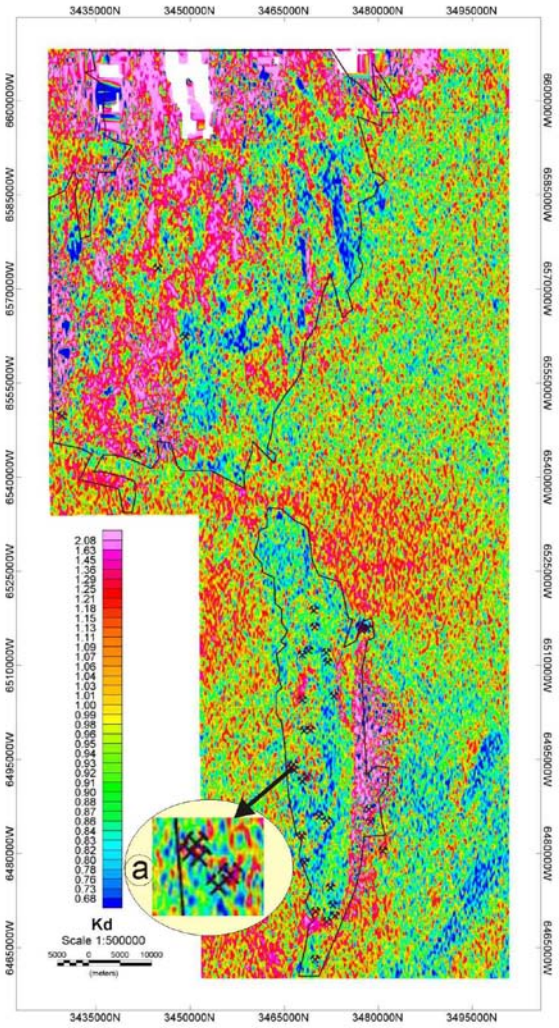

Fig. 4. Kd map with location of gold deposits. In a) In particular the fields of mining district Las Callanas.

Observation of the F parameter map (Fig. 3) showed that the anomalous areas of the parameter F are closer to lode gold occurrences known in the region studied. We have integrated the information from the three maps
(Th / K, Kd, and the parameter F) to highlight anomalous hydrothermal areas in the study region and define the feasibility of minerals. The integration of these data can be done in several ways (eg, An et al., 1991; Agterberg and Bonham-Carter, 1999; Quadros, 2000), but the easiest is to build a map ternary RGB (Red, Green, Blue, in English). However, for a better view, it is necessary that all the initial information is correlated in the same direction (positive anomalies are correlated).

An inversion in the ratio Th / K could be proposed to achieve a better correlation between information, so that high values of K / Th indicate hydrothermally altered areas in the region studied (Fig. 5). Then, we construct the map ternary RGB, assigning R to Kd, G for the parameter F, and B to K / Th.

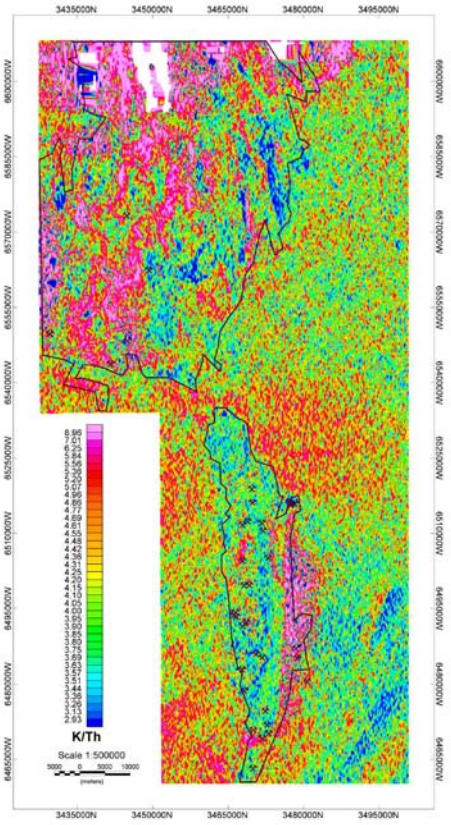

Fig. 5. Map of K / Th with location of gold deposits.

The resulting map (Fig. 6) highlights hydrothermal areas, where all information is linked directly (among the three variables). So white areas indicate high mineral feasibility of vein-type gold deposits. There is also a high correlation between Kd (R) and K / Th (B), and are seen as areas of purple to indicate hydrothermal areas.

In all the figures we can see the difference in the Sierra de las Minas, which occurs to the east of it coinciding with the mylonite Ulapes

Conclusions

The data processing methods of aerial radiometric gamma rays were able to reveal areas enrichment-related hydrothermal K as a target for gold vein type deposits. This result can be verified by the close association between the known occurrences of gold veins in the region studied and the K hydrothermal emphasized through processing methods applied.
Thus, it was shown that hidrotermalizadas areas were highlighted by the high values of F and Kd parameters and by the low values of Th / K.
Data integration feasibility of minerals can be easily performed through a ternary map RGB. This integration of data (R = Kd, G = parameter F, and B = K / Th) was able to focus on areas with high feasibility, displayed on the map with white ternary (three relations are correlated positively), and the areas of feasibility medium purple manifest (just R = Kd and B = K / Th are correlated).

Fig. 6. Aerogammaspectrometric ternary Map, locating gold mines and prospects. Red Channel: Kd Map; Green Channel:Factor F Map; Blue Channel: K/Th Map.

References

Adams, J.A.S., and P., Gasparini (1970). Gamma ray spectrometry of rocks: 295 p., *Elselvier Publ. Co.,* New York.

Agterberg, F. P., and G.F., Bonham-Carter (1999). Logistic regression and weights of evidence modeling in mineral exploration, *in Computer Applications in the Mineral Industries: Proc. 28th Intern. Symp. APCOM'99*, p. 583–590.

An, P., W. M. Moon, and A. Rencz (1991). Application of fuzzy set theory for integration of geological, geophysical and remote sensing data: *Can. Jour. Exploration Geophysics,* **v. 27**, no. 1, p. 1–11.

Briggs, I. C. (1974). Machine contouring using minimum curvature. *Geophysics*, v. 39, No. 1, p. 39-48.

Cravero, O.V. y J.A., Ríos Gómez(1988). Distrito Minero El Abra,Provincia de La Rioja: Un ejemplo de zona de cizalla aurífera (shear zone). en nuestro pais. *Tercer Congreso Nacional de Geología Económica*, Tomo 3, 129–140.

Chambers, P. (1996). Survey details, technical specifications and survey logistics report for airborne geophysical survey Córdoba, La Rioja, San Luis.

Australian Survey Organisation, Geoscientific Mapping of the Sierras Pampeanas Argentine-Australia Cooperative Project.

Dickson, B. L., and K. M., Scott (1997). Interpretation of aerial Gamma-ray surveys adding the geochemical factors: *AGSO Jour. Australian Geology & Geophysics*, v. 17, no. 2, p. 187–200.

Efimov, A. V. (1978) Multiplikativniyj pokazatel dlja vydelenija endogennych rud aerogamma-spectrometriceskim dannym, in *Metody rudnoj geofiziki: Lenigrad, Naucnoproizvodstvennoje objedinenie Geofizica Ed.*, p. 59–68.

Fornazzari, L. N., F.J.F., Ferrreira y A.F., Campos, (2001). Gamma espectrometría aplicada à prospecção de ouro na Folha Botuverá-SC. In: *Congresso Internacional da Sociedade Brasilera de Geofísica*, 7, Salvador. *Proceedings...* p. 621-624.

Frey, M., J. C., Hunziker, J. R., O'Neil, and H. W., Schwander(1976). Equilibrium-disequilibrium relations in the Monte Rosa Granite,Western Alps: petrological, Rb-Sr and stable isotope data: *Contr. Mineralogy and Petrology*, v.55, no. 2, p. 147–179.

Galbraith, J. H., and D. F., Saunders (1983). Rock classification by characteristics of aerial gamma-ray measurements: *Jour. Geochemical Exploration*, v. 18, no. 1 p. 47–73.

Gnojek, I., and A., Prichystal (1985). A new zinc mineralization detected by airborne gamma-ray spectrometry in Northern Moravia (Czechoslovakia): *Geoexploration*, v. 23, no. 4, p. 491–502.

Hoover, D. B. and H. A., Pierce (1990). Annotated bibliography of gamma-ray methods applied to gold exploration: *U.S. Geol. Survey Open-File Rept.* 90–203, 23 p.

I. A. E. A. Report, Exploranium, 1991, Airborne gamma-ray spectrometer surveying: *Tech. Rept.* 323, 122 p.

JICA-MMAJ, 1993. Informe sobre la exploración de minerales del área oeste de la República Argentina – Fase I. Japan International Cooperation Agency, Metal Mining Agency of Japan, Report 93-043. 167 páginas.

Matheron,G .(1963). Principles of geostatistics: Econ. *Geology*, v. 58, no. 8, p. 1246–1266

Naylor, M. A., G., Mandl and C. H. K., Supesteijn (1986). Fault geometries in basement-induced wrench faulting under different initial stress states: *Jour. Structural Geology*, v. 8, no. 7, p. 737–752.

Pankhurst, R.J., C.W., Rapela, J., Saavedra, E., Baldo, J., Dahlquist e I, Pascua (1996). Sierras de Los Llanos, Malanzan and Chepes: Ordovician I and S-type granitic magmatism in the Famatinian Orogen. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas V, p. 415.

Pankhurst, R.J., C.W., Rapela, J., Saavedra, E., Baldo, J., Dahlquist, I, Pascua and C.M, Fanning (1998). The Famatinian magmatic arc in the central Sierras Pampeanas: an Early to Mid-Ordovician continental arc on the Gondwana margin. *The Proto-Andean Margin of Gondwana.* In: Pankhurst, R.J., Rapela,C.W. (Eds), Geological Society of London Special Publications,142 pp. 343–367.

Pieters, P., R.G, Skirrow and P., Lyons (1997). *Informe geológico y metalogénico de las Sierras de Chepes, Las Minas y Los Llanos - Provincia de La Rioja.*, 1: 250,000. Instituto de Geología y Recursos Minerales, SEGEMAR, Buenos Aires, Anales 26.

Pires, A.C.B. (1995). Identificacao Geofisica de Areas de Alteracao Hidrotermal, Crixás-Guarinos, Góias: *Revista Brasileira de Geociencias*, v. 25, no. 1, p. 61–68.

Quadros, T. F. P. de (2000). Integracao de dados para pesquisa mineral de ouro em ambiente SIG na Ilha Cristalina de Rivera, Uruguai. Tese de Doutoramento, PPGEM, Escola de Engenharia:Universidade Federal do Rio Grande do Sul, Porto Alegre, 260 p.

Quadros, T. F. P. de et al. (2003). Gamma-Ray Data Processing and Integration for Lode-Au Deposits Exploration. Natural Resources Research, Vol. 12, No. 1, p. 57-65.

Ríos Gómez, J.A., J., Loredo, y J., García Inglesas (1992). Características mineralógicas de depósitos auríferos ligados a zonas de cizalla (La Rioja, Argentina). *VIII Congreso Latinoamericano de Geología, Salamanca, España*, 4, 242–246.

Saunders, D. F., J. F., Branch, and C.K, Thompsom, (1994). Tests of Australian aerial radiometric data for use in petroleum reconnaissance: *Geophysics*, v. 59, no. 3, p. 411–419.

Saunders, D. F., S.A., Terry and C.K., Thompsom (1987). Test of National Uranium Resource Evaluation gamma-ray spectral data in petroleum reconnaissance: *Geophysics*, v. 52, no. 11, p. 1547–1556.

Saunders, D. F., K. R., Burson, J. F., Branch and C.K., Thompsom (1993). Relation of thorium-normalizaded surface and aerial radiometric data to subsurface petroleum accumulations: *Geophysics*, v. 58, no. 10, p. 1417–1427.

Shives, R. B. K., B.K., Charbonneau and K.L., Ford (1997). The detection of potassic alteration by gamma ray spectrometry recognition of alteration related to mineralization, in Exploration 97, Fourth Decennial Intern. Conf. Mineral Exploration, (Toronto, Canada), p. 345–353.

Swain, C. J. (1976). A FOTRAN IV program for interpolating irregularly spaced data using the difference equations for minimum curvature. Computers & Geosciences, Vol. 1, pp. 231-240.