



**Universidade Federal do Rio Grande do Norte
Centro de Ciências Exatas e da Terra**

PROGRAMA DE PÓS-GRADUAÇÃO EM GEODINÂMICA E GEOFÍSICA

**PROJETO BRASIL/CANADÁ
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**REMOTE SENSING DIGITAL IMAGE ANALYSIS
AND INTERPRETATION STRATEGY FOR
GROUNDWATER EXPLORATION
IN SEMI-ARID CRYSTALLINE TERRAINS:
PROPOSAL FOR A CASE STUDY IN NE BRAZIL**

**Natal
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**REMOTE SENSING DIGITAL IMAGE ANALYSIS AND INTERPRETATION
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INTRODUCTION

Water resources remains a most critical aspect for social and economic development in the semi-arid hinterland of NE Brazil. In the longer, dry seasons, and apart from fewer areas close to large dams, the water for human usage is essentially provided by subsurface reserves stored either in clastic, sandstone-type (associated to the Cretaceous interior or marginal basins) or alluvial-type aquifers, and especially in fractured Precambrian crystalline rocks which are the dominant type of geological terrain throughout the region.

Hydrogeological prospecting in NE Brazil and other crystalline terrains is based on a structural framework which demands a significant update. In this kind of terrain, water percolation and accumulation is essentially controlled by fractures and other rock discontinuities. In order to build a new conceptual model to support water prospecting, it is necessary to consider a number of topics such as fracture geometry (including their aperture and connectivity) and chronology, as well as the crustal level of the brittle deformation, which have to be placed within a regional framework while being evaluated during water well site location. Different fracture systems may be present at each place, aging from the end of the last Precambrian orogeny (the so-called Brasiliano cycle) to the mid-Cretaceous rifting and subsequent continental drift, besides reactivations during late Cenozoic times. As exploitable water migration and accumulation is a very young process, in due course in the uppermost crustal levels, neotectonic stress fields certainly exert an important control in it. Weathering processes can also influence “opening” of fractures and other rock discontinuities, such as foliation planes, sometimes in an anisotropic pattern which reflects a neotectonic control.

Classical techniques for groundwater prospecting bear a strong emphasis in the examination of aerial photographs, in order to map regional and/or local fracture

patterns and to evaluate their hydric potential - this means, recharge conditions in relation with the drainage network and the topographically-controlled surficial runoff.

Research programs at Rio Grande do Norte and other places in NE Brazil (especially Ceará and Pernambuco), sponsored by governmental brazilian and, more recently, canadian agencies, have repeatedly addressed the usage of the classical aerial photographs with common scales ranging from 1:20,000 to 1:70,000. In mapping fracture sets, very good results are obtained in the best exposed, drier areas, with the larger scale rank pictures. At the other side, 1:70,000 scale photographs from deeply weathered areas closer to the coast offer much poor results. In all cases, the classical structural interpretation based on aerial photographs (essentially providing lineament maps) may differ significantly from the ground structural evaluation at the scale of a water well.

Up to now, our experience with a number of case studies suggests that “regional” (at 1:50,000 to 1:100,000 scale, based on visual interpretation of photographs and Landsat 5-TM imagery) lineament maps and especially, the several statistical “by-products” derived from it (such as lineament densities, lineament intersection densities and so on), do not assure high water yields from the located wells. One is thus faced with two possible approaches: a) to give a stronger emphasis to structural analysis at the outcrop scale; b) to work out possible refinements in the methodology of analysing different remote sensing products, taking into account their intrinsic limitations and optimizing digital treatment techniques, together with a careful reappraisal of geological data relevant to the problem. This last approach is the one chosen to be developed during a 3-month research/working program in Canada, emphasizing the application of RADARSAT imagery, comparison with multi-look and multi-temporal SAR images and remotely sensed multi-source data integration.

THE GROUNDWATER RESEARCH PROJECT IN THE PRECAMBRIAN TERRAINS OF RIO GRANDE DO NORTE

This research project began late in 1997, sponsored by the brazilian PADCT program with additional support from State agencies and conducted by geoscientists and graduate students of the *Programa de Pós-Graduação em Geodinâmica e Geofísica da Universidade Federal do Rio Grande do Norte (PPGG/UFRN)*, at Natal. Three areas

were chosen for testing different techniques aiming to improve simple methodological criteria for groundwater prospecting. This involves geological-structural mapping at different scales, emphasizing both field and remote sensing techniques, combined with geophysical methods (resistivity, EM, GPR, etc.).

The studied areas include (figure 1):

- a) Santo Antonio-Serrinha villages, located closer to the eastern Atlantic coast and subjected to a more humid climate, where crystalline outcrops - mostly gneisses and granitoids, are scattered throughout important, decametric-thick soil/aluvial/colluvial cover in a low relief landscape;
- b) Santa Cruz village, in the transition to the dry hinterland, where gneissic rocks outcrop once more and finally
- c) Equador village, in the very dry, desertic hinterland in the central part of the State, where amphibolite facies metasediments extensively outcrop.

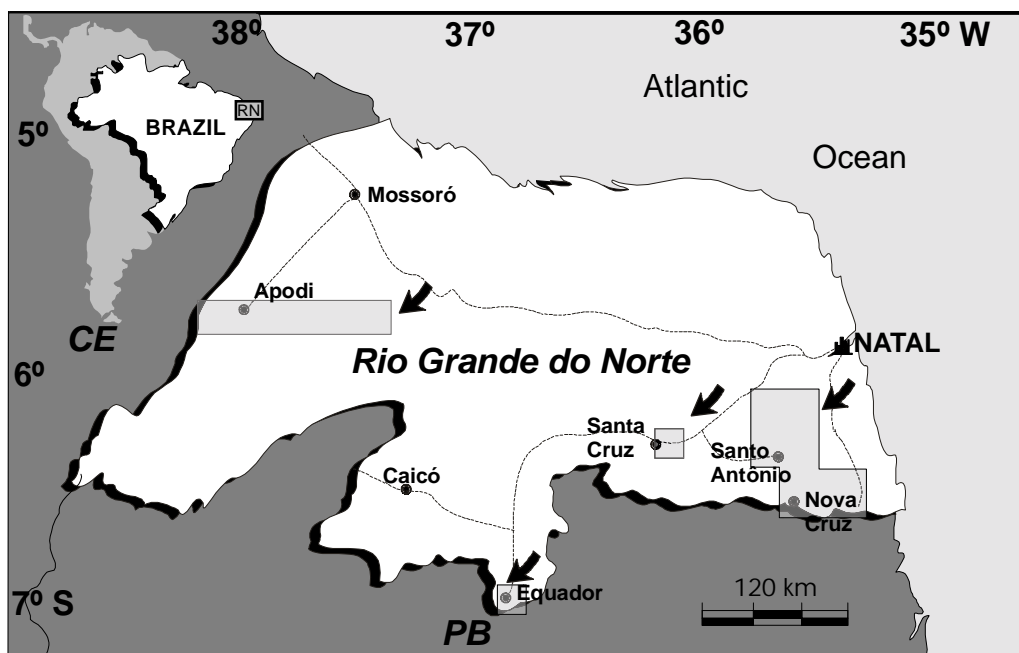


Figure 1- Geographic location of the studied areas.

In these areas, digitalized aerial photographs and Landsat 5-TM imagery were used to compile lineament maps. Previous water well sites, located by governmental or private hydrogeology teams according to the classical techniques, are being re-evaluated in terms of field structures and relation to photointerpreted lineaments. Field work emphasizes the different fracture sets and, wherever possible, neotectonic

reactivation features. Combined with geophysical data, different models of water accumulation may be conceived at each site, given different weights to the following end features: a) the presence of rectilinear, fracture-controlled river tracts (the so-called “riacho-fenda” model); b) the presence of thicker, alluvial-colluvial cover overlying rocks whose structural discontinuities (fractures and foliations) were “opened” by near surface weathering.

This study also includes a fourth area with semi-arid conditions, but in this case encompassing Cretaceous sediments (sandstone-type aquifer) overlying crystalline basement terrains in the southern border of the Potiguar Basin, between Apodi and Upanema villages.

EVALUATING THE CONTRIBUTION OF REMOTE SENSING TECHNIQUES TO GROUNDWATER EXPLORATION IN SEMI-ARID CRYSTALLINE TERRAINS

The title above summarizes the objectives of the proposed research plan. It involves a 3-month stay in Canada for a Brazilian PhD student, preceded and followed by appropriate work by the project team at NE Brazil. The stay in Canada will focus on examining:

- (1) The application of automatic procedures (including image enhancement spatial filtering to edge detection and texture analysis, radar stereoscopy, etc.) to map lineaments in RADARSAT various beam modes images (standard and/or fine modes); comparison to other remote sensing images such as Landsat 5-TM and digitalized aerial photographs submitted to similar digital procedures; the spatial relation of productive and non-productive water wells as regards to visually interpreted lineaments will be evaluated as well;

- (2) The possibility of evaluating relative moisture and water leakage points of different fracture sets and major lineaments, throughout detection of changes in multi-temporal Landsat images based on color composition (RGB and IHS color space) of multispectral visible-infrared bands; if possible, this will include an statistical assesment of the moisture/hydric potential of fracture sets with different orientations;

- (3) Thematic mapping of different surficial covers in terms of their clay-content and/or coarser sand clastic fraction, and their role in promoting or locking water recharge in nearby lineaments;

(4) Correlation of the lineament framework and their hydric potential with a wide range of geological-geophysical data, including chronological markers and neotectonic stress fields.

An important part of the research will be to develop a simple methodological approach by which geologists, even not being specialists in remote sensing techniques, could request and employ this kind of information during routine regional exploration and water well site location.

METHODOLOGICAL APPROACH DURING THE RESEARCH PROGRAM AT CANADA

The following steps are envisaged on a preliminary basis:

1. Preprocessing techniques applied to RADARSAT images (standard and/or fine mode, due to 25 m to 8 m spatial resolution, respectively) of Santo Antônio (35°15'W, 35°40'W - 6°05'S, 6°35'S), Santa Cruz (35°58'W, 36°02'W), Equador (36°39'W, 36°45'W - 6°52'S, 6°57'S) and Upanema-Apodi (37°00'W, 38°20'W - 5°30'S, 5°50'S) areas (Rio Grande do Norte State, NE Brazil): radiometric corrections and enhancement, orthorectification and speckle filtering reduction;
2. Preprocessing of Landsat 7-ETM+ (or *Landsat-type*) images of the same areas: geometric, atmospheric and radiometric corrections;
3. Digital image analysis and interpretation of RADARSAT and *Landsat-type* corrected and coregistered images to enhance interesting textural elements and structural features, moisture detection and moisture vs. fracture patterns correlations applied to groundwater exploration; high frequency spatial filtering with directional illumination to enhance the lineaments patterns; surficial covers and moisture detection based on integration of color composites multispectral bands (texture analysis, RGB and IHS colour space, ratio, principal components analysis, supervised and unsupervised classification, change detection, etc.) to determine clay-content and/or coarser sand clastic predominance, and moisture/soil/vegetation/fracture pattern association;
4. Analysis of RADARSAT stereo pairs to provide detailed 3D perspective views of terrain landforms (DEM generation) and enhancement of subtle textural/structural patterns; the terrain landform slopes and altitude varies from one study area to another but RADARSAT images on fine mode from same-side (i.e., descending-

- descending or ascending-ascending) with large overlap is recommended;
5. Merging of coregistered distinct spatial resolution images (*Landsat-type*, digitalized aerial photos) in different scales;
 6. Integration of RADARSAT and *Landsat-type* images with geophysical data in order to evaluate spatial continuity (regional and subsurface) of textural and structural elements enhanced at the surface;
 7. GIS structure development merging raster images (thematic and classified images) coregistered with some other data in vector format (well location maps, geologic and structural data, hydraulic data, etc.) to provide an improvement on qualitative and quantitative data consultation to validate favorable places to groundwater accumulation and well locations.

CURRENT CAPABILITIES AT PPGG/UFRN LABORATORY

The PPGG/UFRN has a remote sensing and GIS laboratory equipped with Pentium-III Processor PC's (64-128 MB, 200-450 MHz, 15"-17"video) and scanning/printing devices, with ER-Mapper v.6.2 and ArcView/Arc INFO softwares. The remote sensing lab own a collection of multi-date and multi-scale analog and digitalized aerial photos and Landsat 5-TM and Landsat 7-ETM+ images of Northeast Brazil.

MATERIAL SUPPORT REQUIRED

The project requires RADARSAT scenes (standard and/or fine modes) of ascending and/or descending orbit, and RADARSAT stereo pairs on same-side or opposite side configuration, with large intersection angle. In order to effectivate all methodological techniques on geometric and radiometric corrections and enhancement of RADARSAT images, a PCI software educational license to PPGG/UFRN is desirable.

RESEARCH TEAM DIRECTLY INVOLVED IN THIS PROPOSAL

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