3D-Modeling of the Santa Terezinha Coalfield, Brazil: Assessment of Coal Bed Methane Potential

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1. Abstract

In Brazil, economically important coal-measures occur in the southern Paraná Basin. Their proven reserves amount up to 32 billion tons. From all coal fields in the Paraná Basin, the Santa Terezinha field in Rio Grande do Sul state appears to have the highest CBM potential based on coal rank, coal distribution and depth of the coal seams. The coal measures dip at an angle of 3° to the NW. In addition to that, they are downthrown at a set of NW-SE striking normal faults towards the trough of a grabenlike structure ("Torres syncline"). The coal measures occur near surface and at depths down to 950 m. Coal seams area hosted in a succession of sandstones, mudstones, and shales of Early Permian age. Sequence stratigraphy was applied in order to subdivide this succession and to correlate the coal seams. Four coal bearing parasequences have been identified showing a cumulative coal thickness up to 10 m. The most important controls for the CBM potential are a) basin geology, i.e. reservoir size, depth and thickness of coal seams; b) coal characteristics, i.e. coal rank, coal type and coal grade; c) in-situ methane content, measured by means of gas desorption tests and isotherm adsorption tests. To make an assessment of the CBM potential of the coal-bearing strata, computer-aided modeling of the Terezinha Coalfield was carried out using the Surpac system by Surpac Software International of Perth, Western Australia. Computerized modeling packages are mainly used on the scale of a single deposit. Here, we want to show that such systems are also powerful tools in large-scale exploration projects. The resulting model will provide a vital decision support for locating a first coalbed methane test well.

2. Introduction

Coal bed methane (CBM) is a worldwide exploration target of the petroleum industry. Currently, it is produced profitably only in a number of coal basins in the United States. In Brazil, the economically most important coal-measures occur in the southern part of the Paraná Basin. Since the begin of the 20th century, the states of Santa Catarina and Rio Grande do Sul (Fig. 1) are renown for their abundant and important coal deposits. The Paraná Basin is a large intracratonic basin located on the central-eastern part of the South-American Platform (Fig. 1) covering an area of about 1,700,000 km^2. Its subsidence during the late Paleozoic may be explained by subduction processes at the Panthalassan margin of Gondwana. Based on the results of numerical models, PYSKLYWEC & QUINTAS (2000) proposed the hypothesis that stiff subducted slabs can accumulate at the 660 km phase transition. The accumulated material became unstable intermittently resulting in a flux into the lower mantle. The local downward flow induced surface normal stresses which led to a subsidence in the overlying continental crust. Between the Late Ordovician and the Upper Cretaceous the basin was filled with sedimentary and intrusive sequences reaching a maximum thickness of 7000 m (MILANI & ZALÁN 1999). Six second-order depositional sequences or supersequences are distinguished (MILANI 1997). Three super-sequences comprise Paleozoic transgressive-regressive cycles, the remaining ones include Mesozoic continental sediments as well as basaltic rocks. The coal-bearing strata are part of the third sequence, namely the Carboniferous/Eo-Triassic Sequence which represents the thickest sequence in the basin (approx. 2800 m). Stratigraphically, the coal measures belong to the Rio Bonito Formation, a fluvial to marine sand- and shale-prone lithostratigraphic unit of Early Permian (Artinskian-Kungurian) age.

From all coal fields in the Paraná Basin, the Santa Terezinha field in Rio Grande do Sul state appears to show the highest CBM potential. A resource appraisal would provide the necessary support for a decision to start tapping this domestic energy resource. To assess the CBM potential a study area of ca. 5000 km^2 has been selected at the south-eastern margin of the Paraná Basin. Between the seventies and early eighties of the last century it was the target area for a coal exploration by Companhia de Pesquisas de Recursos Minerais (CPRM), the Brazilian geological survey.

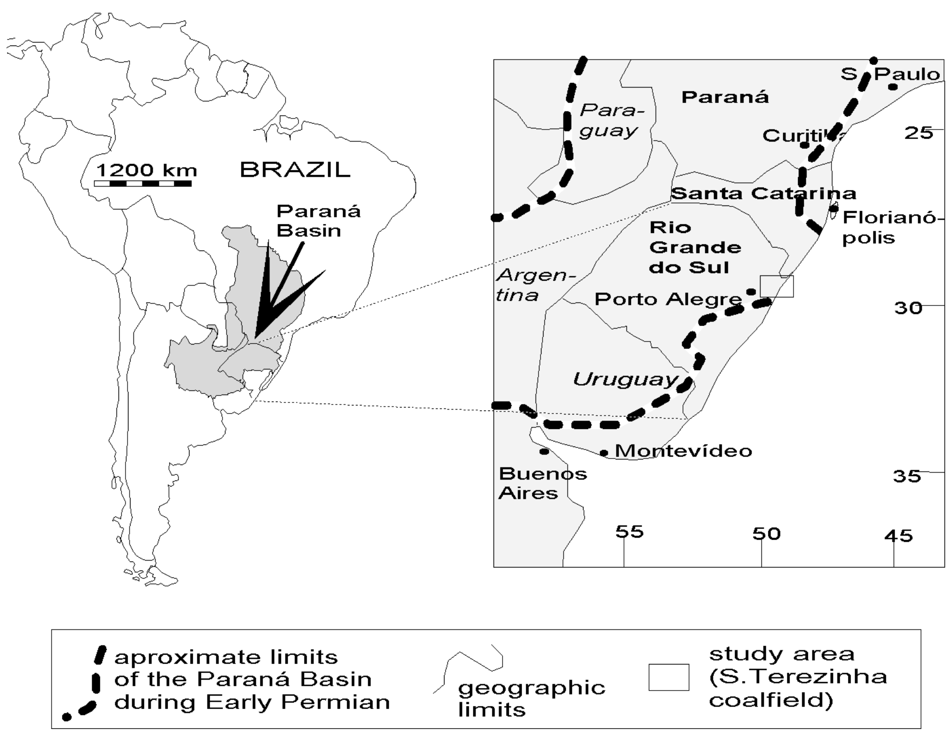

Fig. 1: Location map

3. Coal distribution and depositional environment

Thin (< 0,5 m) and laterally discontinuous coal seams are found in a fluvial facies association characterized by orthoconglomerates and coarse to fine subarkose sandstones, with planar and trough cross bedding and fining-upwards cycles, ending in mudstones and coal. The interfluves are characterized by a muddy facies with argillaceous coal seams.

The up to 2.5 m thick and laterally continuous (up to 40 km) coal seams occur in association with fine sandstone and mudstone with lenticular and wavy bedding. Paleosoils characterized by nodular mudstone with rootmarks occur in several levels within the mudstone-coal facies. Dip-directed correlation sections show that this coal-bearing facies is laterally and vertically associated with fine to medium quartz-rich sandstones, forming units with thicknesses of up to 12 m. The most conspicuous sedimentary structures are tabular cross stratification and planar-parallel bedding, flaser levels, mud drapes and wavy bedding, and abundant swaley and hummocky cross stratification.

The features of the facies framework point to a barrier-lagoon depositional system, where the mires were formed behind barrier islands. The muddy facies with coal seams were formed in lagoonal waterbodies during periods of inlet restriction. Insofar, the most important and economically valuable coal seams, were formed in coastal mires controlled by important base level fluctuations.

Sequence stratigraphic analysis has shown that the coal-bearing succession can be divided into 6 fourth-order parasequences: one forms the fluvial and estuarine lowstand systems tract, four parasequences are linked to the transgressive systems tract formed by barrier-lagoon systems, where the important coal seams occur, and one parasequence forms the highstand systems tract, with minor and non-economic coal layers. The sequence stratigraphy of the coal-bearing interval is summarized in HOLZ et al. (2000).

The coal seams are hard to correlate on a lithostratigraphic basis because they are somewhat discontinuous and frequently show pinchouts and splittings. The problem has been solved by using the parasequences as a correlation tool: the flooding surfaces of the parasequences have been depicted in each borehole and correlated throughout the Santa Terezinha Coalfield and the adjacent Chico Lomã and Gravataí coalfields, resulting in a stratigraphic framework with permitted adequate correlation of the coal seams within every parasequence.

4. Geometric modeling of Santa Terezinha Coalfield

To make an assessment of the CBM potential of the coal-bearing strata, computer-aided modeling of the Terezinha Coalfield was carried out using the Surpac system by Surpac Software International (Pty.) Ltd. of Perth, Western Australia. Surpac is an integrated geoscientific modeling system for mine planning and environmental engineering. It offers the necessary software tools for geometric modeling of geological objects, property modeling, mine planning as well as groundwater modeling. Within Surpac, a number of representation schemes with different expressive power may be used for the digital description of 3D objects:

- Wireframe models (string models) allow geologists to interactively set up models of geological features like outcrop lines, geological surfaces and bodies. This is a fast and convenient method to describe geological objects by their edges. However, wireframe models lacks the topological information to safeguard the validity of surfaces or bodies. For further processing, they have to be transformed into models based on representation schemes with a greater expressive power.
- Surface models are stored as triangulated irregular networks (TINs), called digital terrain models or DTMs. In general, DTMs are created from string models. In addition to that, Surpac offers interactive triangulation tools.
- Volume models are based on the Boundary Representation (BRep). The bodies under consideration are described by their hull decomposed into planar triangles. Surpac uses the term 3DM when referring to this class of objects. The data structure guarantees that only valid bodies can be generated.
- To describe the spatial distribution of properties within a geological object (either a body or a region between two surfaces) octree-based 3D variable block models are employed.

Generation of the geometric model of the Santa Terezinha Coalfield started with setting up a model of the topography. Afterwards, the top of the basement was modeled. Most drillhole logs showed that the basement is directly overlain by the coal bearing sequences. In a third step, models for the upper and lower enclosing surfaces of six parasequences will be created. For the assessment of the CBM potential, it may also become necessary to incorporate the geometry of the dykes into the model.

We decided to employ published historic data for the interpretation of the tectonic structure of the basement. This way, vital parameters could be predicted without any further exploration effort. The data set, made available for this study, comprised 126 cored holes with a total length of 53666 m.

Lithological logs were preserved for 93 drillholes, one hole had to be rejected due to an inaccurately recorded collar location. Outcrop and subcrop lines of the basement as well as a section through the Terezinha Coalfield provided further information on the structure of the study area.

The dominant tectonic structure in the study area is the NW plunging grabenlike depression historically labeled the "Torres Syncline". According to PADILHA & VITORELLO (2000) it is characterized by a set of faults at which downward movements of the basin sediments took place. To get an impression of the structure of the basement 27 sections in the NE-SW direction were constructed. The distance between most sections is 2000 m. In areas of a low drillhole density the distances were increased to 3000 or 4000 m. All sections gave clear evidence for the existence of steep normal faults with vertical displacements between 30 and 250 m and relatively small horizontal displacements in the northeasterly direction. The faults affected the basement as well as the coal measures. It is not yet clear if or to what degree they dislocate the overlying Mesozoic strata. A typical section, prepared using the Lynx package by Lynx Geosystems S.A. (Pty.) Ltd. of Johannesburg, is depicted in Fig. 2.

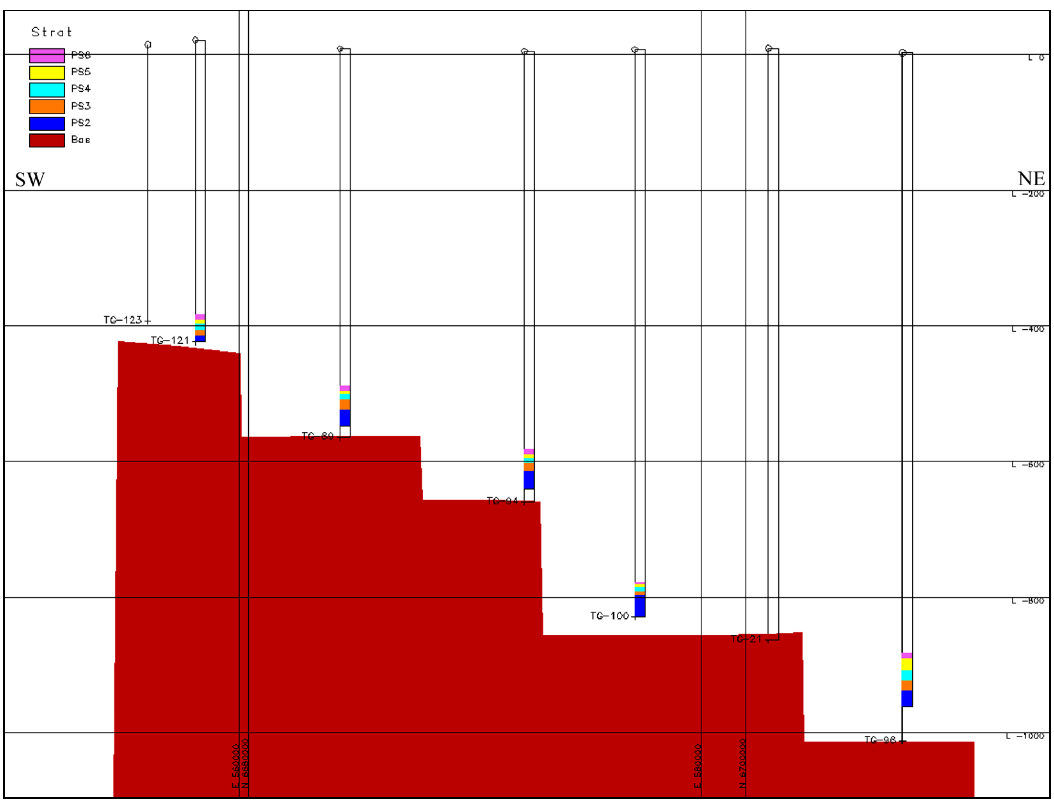

Fig. 2: SW - NE section through the SW hinge of the “Torres Syncline” (vertical exaggeration: 40 times)

In the next stage of model building, crests and toes of the faults shown in the sections were interactively correlated. This resulted in a wireframe model showing the fault surfaces and the top of the basement. In general, the basement dips at an angle of 3° to the NW. Towards NE it is downthrown at a set of NW-SE striking normal faults. It seems that the northwestern part of the area under study has been dislocated at a younger NE-SW striking dip-slip fault. The model reflects the regional geology, as described by PADILHA & VITORELLO (2000) very well. Additional drillholes could help to locate the trough and also to incorporate the lower parts of the NE hinge of the trough. The basement occurs at depths between –15 and –950 m (NN). An impression of the structural model is given in Fig. 3.

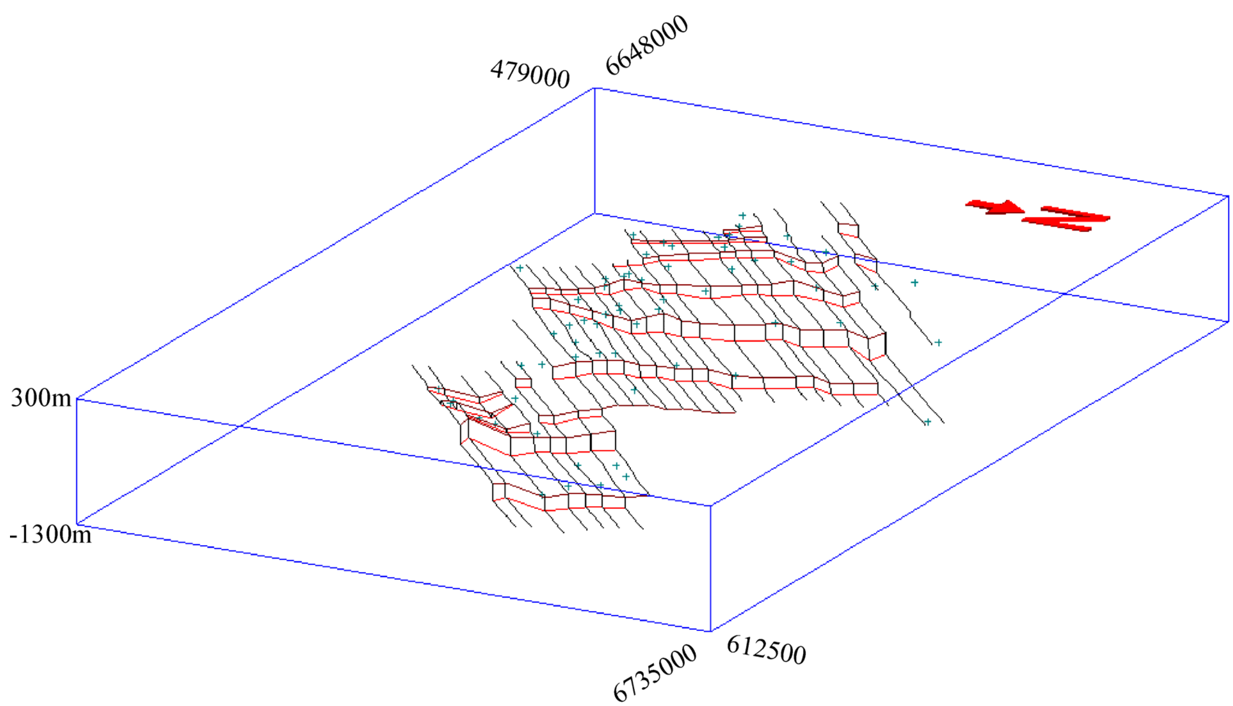

Fig. 3: 3D view of the wireframe model of the basement in the SW hinge of the "Torres Syncline" (from NE, vertical exaggeration 15 times) (black: sections, red: upper and lower boundaries of fault planes, green: basement intercepted by drillholes)

The completed geometric model will form a vital input for the subsequent analysis and estimation of the spatial distribution of coal properties. Later on, the geometry and the property model will be used to estimate the total amount of coal. Based on observed and estimated coal quality parameters, it will enable us to calculate the CBM content for each depth interval.

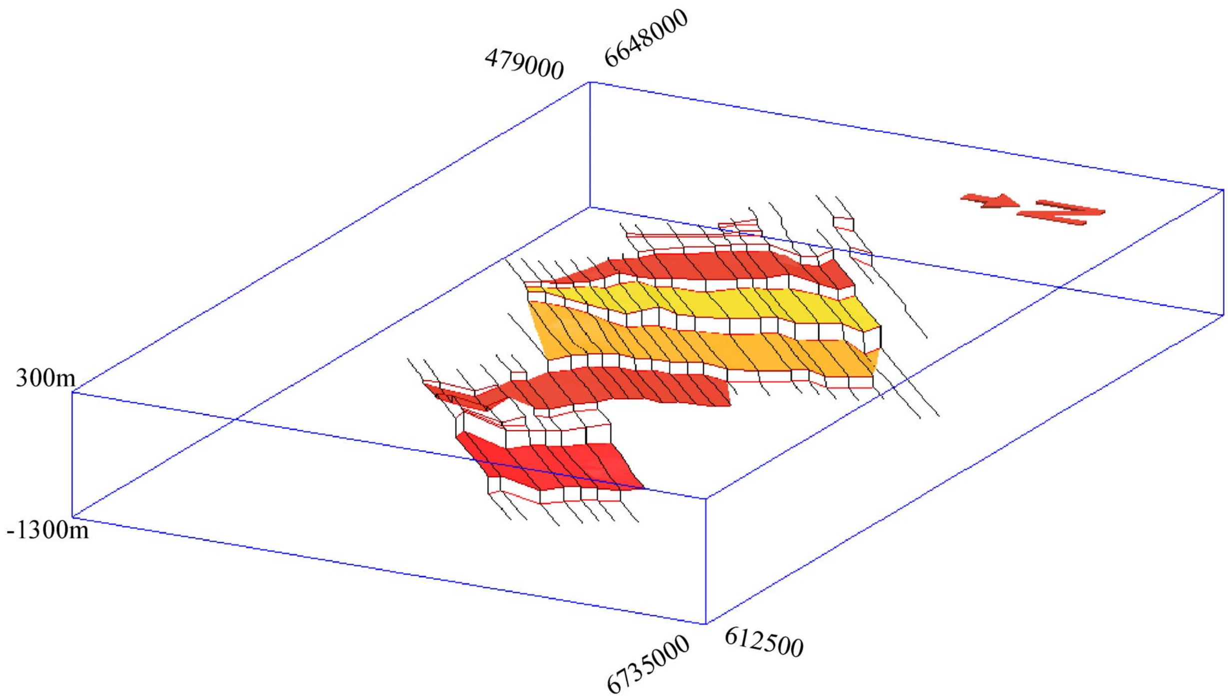

Fig. 4: 3D view of the blocks selected for an assessment of the CBM potential (view from NE, vertical exaggeration 15 times)

5. Estimation of CBM potential

The most important controls for the CBM potential are a) coal characteristics, i.e. coal rank, coal type and coal grade; b) in-situ methane content, measured by means of gas desorption tests and adsorption tests and c) basin geology, i.e. reservoir size, coal distribution (depth and thickness of coal seams, size of undisturbed coal layers). At this point data on coal rank and gas adsorption tests are available and are discussed below.

5.1 Coal rank

Assessment of coal rank at this point is based on vitrinite reflectance measurements of 120 coal samples obtained from 27 borehole locations. Fit of a linear trend surface shows that vitrinite reflectances increase from SW to NE across the coalfield (Fig. 5). The reflectance values (0.53-0.99 % Rrandom) indicate subbituminous to high volatile A bituminous coals. Locally, diabase intrusions have altered the rank of the coal seams to anthracite, with vitrinite reflectances of up to 5.46 % (not shown on Fig. 5).

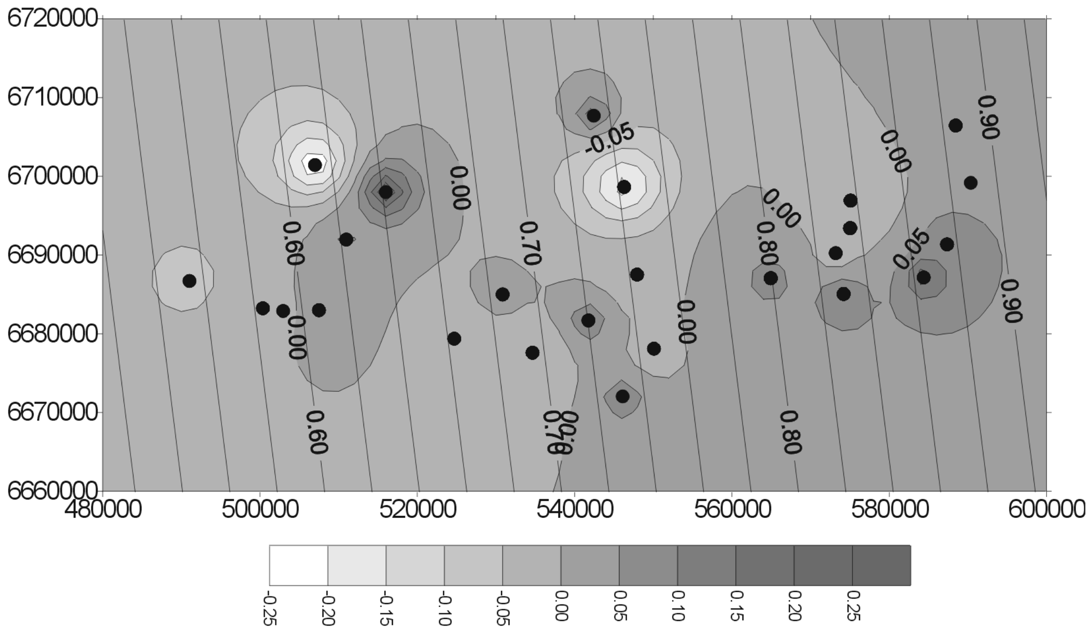

Fig. 5: Linear trend surface map for the Santa Terezinha Coalfield, showing increase of coal rank (vitrinite reflectance) towards the NE and local deviations from the regional trend (residuals).

Based on the vitrinite reflectence distribution the best CBM potential is to be expected in the eastern part of the Santa Terezinha Coalfield (Ro > 0.7 %, see Fig. 5).

5.2 Methane isotherm experiments

Methane Isotherm experiments carried out on a number of coal seam samples indicate: a) in samples with similar vitrinite and mineral matter contents, the highest values of methane adsorption correspond to the highest reflectivity; b) samples with similar rank (reflectivity) and vitrinite content the highest value of methane adsorption correspond to the lowest mineral matter content; c) in samples with similar rank (reflectivity) and mineral matter content the highest methane adsorption correspond to the highest vitrinite content (KALKREUTH et al. 2000). In general the methane adsorption capacities reported here (2 - 6 m^3/ton of coal) correspond to those methane values calculated earlier based on empirical considerations (RYAN 1992) including coal rank, ash yields and depth (KALKREUTH & HOLZ 2000).

5.3 Estimation of CBM potential for selected blocks

For a preliminary estimation of CBM potential we used the 5 "homogeneous" blocks (at this level of information) which can be identified by the geometrical model (see Fig. 4). All drillholes within the borders of these blocks were identified and the following quantities were calculated by simple averages of the corresponding data extracted from the Santa Terezinha data base:

- ✓ mean and maximum vitrinite reflectence *Ro*
- ✓ mean of net total coal seam thickness T_c
- ✓ mean of total coal seam thickness T_t
- ✓ depth range of sampled coal seams d_u, d_l
- ✓ CBM content (estimated from empirical formulas)
- ✓ area *A* of each block (given by the geometric model)

The results of this calculation are listed in Tab. 1.

Block	*Area* Mio m^3	*Mean Ro* [%]	*Max Ro* [%]	T_{coal} [m]	T_{total} [m]	d_u [m]	d_l [m]	*CBM* *[cm^3/g]*
1	288	0.64	0.99	3.76	5.28	197	397	2.13
2	403	0.66	0.80	3.92	6.49	230	343	2.67
3	574	0.73	0.95	3.80	5.19	305	461	3.14
4	366	0.76	0.92	3.13	4.15	463	625	4.28
5	309	0.84	1.03	5.65	6.77	610	902	5.43

Tab. 1: Table of parameters for reserve estimation of CBM for 5 homogeneous blocks derived from geometrical model of Santa Terezinha Coalfield

It is most likely that the coals occurring near surface (< 200 m depth) will have lost their gas. A more detailed study of the drill hole data and the fault system will be necessary in order to further subdivide these blocks into sub-blocks which reveal more favorable parameters than the mean values listed in table 1. For this purpose it may be necessary to evaluate additional drillhole data which are available from the archives of the Companhia de Pesquisa e Recursos Minerais (CRPM), Brazil.

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