3D geological model of the northern Po Plain near Brescia

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ABSTRACT

A 3D reconstruction of the texture distribution of the subsoil in the Brescia plan region is presented. The area is located between the morainic amphitheatres of Iseo westward and of Garda eastward. It is characterised by fluvial and flvioglacial deposits in which the texture sizes decrease southward. The thickness of the sedimentary bodies increases southward. According to geomorphological and pedological considerations, the age of the deposits below the surface is Last Glacial Maximum (LGM). Using a water well data base TANGRAM, developed in the IDPA-CNR Milano, 415 well data are stored, georeferenced and their stratigraphic logs are translated into alphanumeric codes. Textural well data can be translated and imported into GOCAD (Geological Object Computer Aided Design), where a set of 3D special virtual objects is easily constructed. Two surfaces, topography (DTM) and aquifer bottom in the subsoil, are imported into GOCAD from a GIS. Between these two surfaces a 3D grid (SGrid) is reconstructed with 3D cells (Voxel). The wells are located on a DTM and are defined by marker levels which correspond to different stratigraphic layers. The percent of texture size gravel, sand and silt-clay is assigned to each stratigraphic layers of the wells. Using the three dimensional grid, these values are assigned to the nodes of the 3D grid and then processed. In this way, the distribution of texture is calculated for each voxel on the whole 3D volume of the subsoil.

AIMS

The aims of this work are the 3D reconstruction of the texture distribution in a plain area. The aim has been reached using some traditional data (well data organised in a database, topographic map, geomorphologic data), referred to Geographic Information System, and producing statistical and three dimensional elaboration's. Different points have been developed to reach the aims:
- elaboration of geomorphologic detailed map;
- use of stratigraphic well logs as quantitative data;
- creation of codified and georeferenced stratigraphic well path;
- database application to store well data;
- use of three dimensional textural modelling;
- calculation of texture distribution in a 3D subsoil volume;
- future scientific application.

KEY WORDS

Database, well logs, geomorphologic elements, texture of the deposits, 3D elaboration

RIASSUNTO

Scopo di questo lavoro è la presentazione per una area della pianura bresciana della ricostruzione tridimensionale dei depositi che la caratterizzano attraverso la distribuzione delle caratteristiche tessiturali. L'area di pianura compresa tra gli anfiteatri morenici della Franciacorta ad ovest di Brescia e del Garda sul lato orientale dell'area di studio è contraddistinta in superficie dalla presenza di depositi fluviali e fluvioglaciali a granulometria decrescente a partire dal margine alpino verso il limite meridionale dove scorre il Po.
Lo spessore di tali depositi aumenta con continuità dal margine alpino verso il depocentro. L'età dei depositi più superficiali è riferita, sulla base di considerazioni di tipo principalmente geomorfologico e pedologico, al Last Glacial Maximum (LGM). Dati idrogeologici puntuali, relativi a 415 pozzi, sono stati archiviati in Tangram, database sviluppato dal IDPA-CNR Milano. Nel data base le informazioni idrogeologiche, ed in particolare le stratigrafie, sono codificate e georeferenziate. Le informazioni tessiturali dei pozzi sono estratte dalla banca dati e convertite in formato GOCAD (Geological Object Computer Aided Design), creando oggetti virtuali 3D georeferenziati e a ciascun livello stratigrafico dei pozzi è quindi assegnato un valore percentuale delle classi di tessiture: ghiaie, sabbie, limi-argille. I dati areali della zona in esame (topografia e base dell'acquifero) sono stati quindi elaborati in un GIS e successivamente convertiti anch'essi in formato GOCAD. Tra tali superfici è costuita una griglia 3D (SGrid) in cui ciascuna cella (Voxel) assume posizione e forma in funzione delle suddette superfici. A ogni voxel ubicato in corrispondenza dei pozzi 3D georeferenziati è attribuito il valore delle percentuali di ghiaia, sabbia e limi-argille. Utilizzando il "Discrete Smooth Interpolator" (DSI), tali valori sono inoltre interpolati per ogni voxel in tutto lo spazio tridimensionale definito dalle griglie 3D, permettendo la ricostruzione tridimensionale della distribuzione dei valori delle tessiture nel sottosuolo della provincia di Brescia.

GEOMORPHOLOGICAL MAP OF THE BRESCIA PLAIN

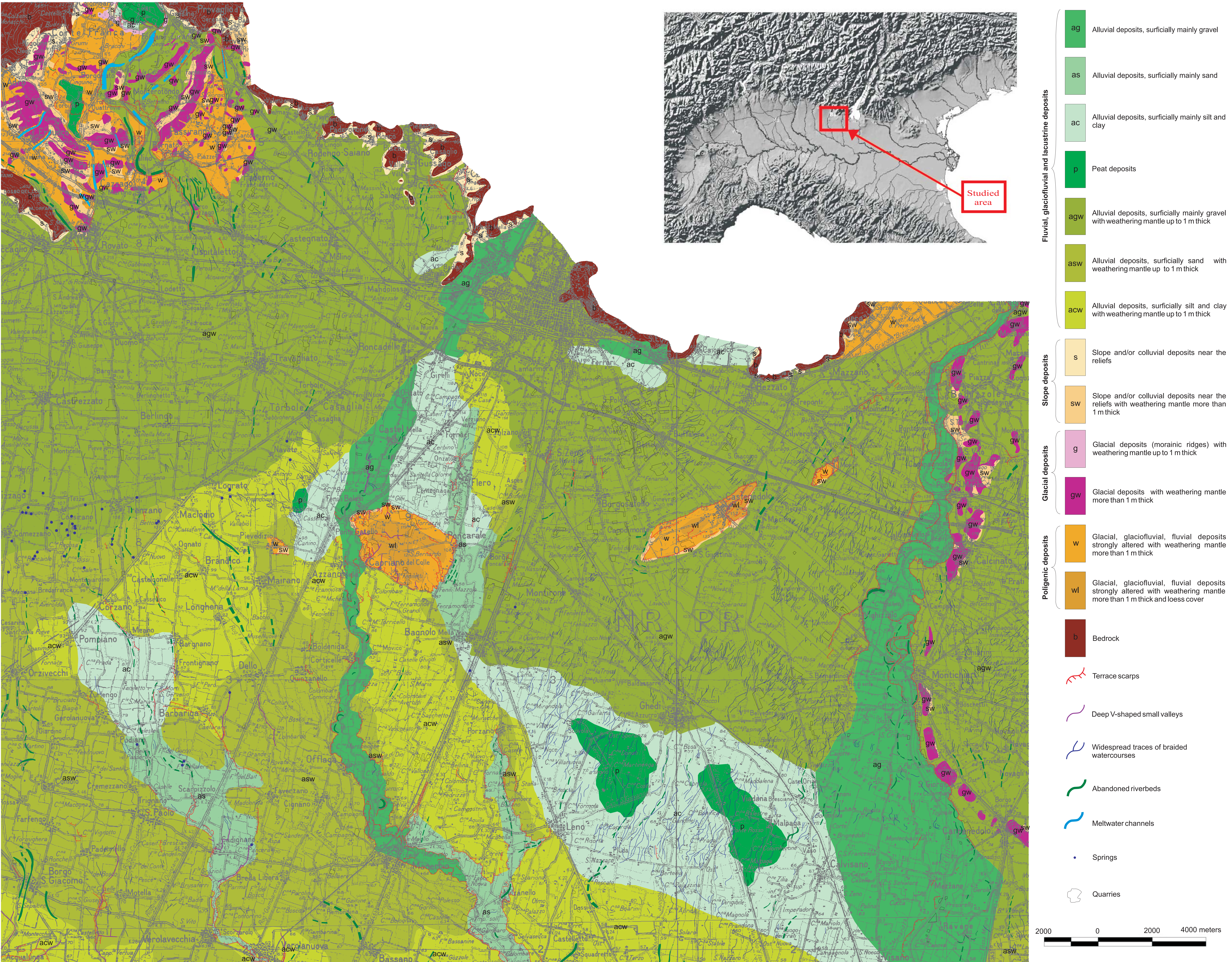


Fig. 1 - *Geomorphological map.*

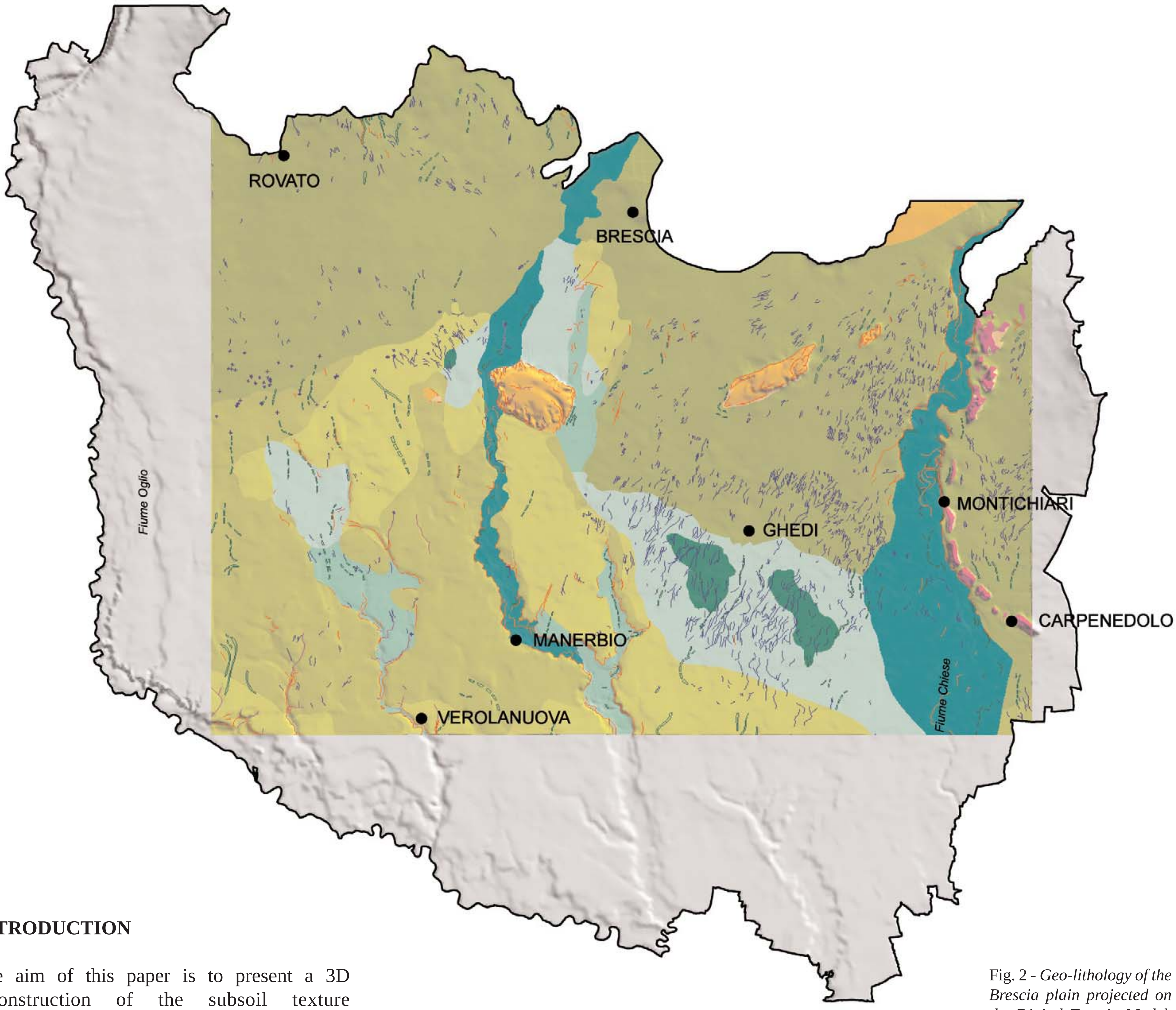


Fig. 2 - *Geo-lithology of the Brescia plain projected on the Digital Terrain Model. For the legend see Fig. 1.*

INTRODUCTION

The aim of this paper is to present a 3D reconstruction of the subsoil texture distribution of the Brescia plain, located in the northeastern side of the Lombardia region (Northern Italy). In a area representative of the central part of the Po Plain and characterised by soils and evidence of fluvial processes on extended surfaces, the detailed knowledge of both geomorphology and subsoil data, has permitted a 3D geological elaboration.

The link between subsoil data, supported by many well logs, and the geomorphology of the plain will enable the representation of 3D parametric elaboration. The representation of subsoil texture enables to investigate if the outcropping gravelly glacial bodies may be recognised also in the deeper levels.

GEOMORPHOLOGIC AND GEOLOGIC SETTINGS

The Brescia plain, located between the moraine amphitheatres of Iseo to the west and Garda to the east, is mainly constituted by fluvial and fluvioglacial deposits, whose texture size decreases southward. On the other hand, the thickness of the deposits increases southward. The evolution of the plain during late Quaternary is strongly influenced by climatic changes that produced significant aggradations during cold stages followed by short but intense fluvial erosion.

The units represented on the geomorphological map (scale 1:100,000 Fig. 1) have been distinguished on the basis of prevalently geomorphological criteria. From the hierarchical point of view, the first element to be considered is the geomorphological process responsible for the deposition of sedimentary bodies (which in this geomorphological map are, respectively: alluvial, glacial, slope and/or colluvial deposits). As a second element, the texture of surface deposits is taken into account (in case of pedogenetic weathering thinner than one metre, the texture of the underlying deposits is considered). Thirdly, the thickness of surface weathering capable of providing a relative dating of the outcropping surfaces is assessed, since this dating does not always coincide with that of the underlying deposits. For this reason, ages have not been included in the geomorphological map’s legend. In the case of weathering levels thicker than one metre, without morphological evidence enabling a clear attribution to a specific modelling agent, the presence of weathering becomes a prevailing criterion. In this sense the units shown here cannot be defined as UBSU (Unconformity Bounded Stratigraphic Units) or as Allostratigraphic Units (quotation from other papers in this volume) but rather as Physiographic Units more similar to Lithostratigraphic Units and, as such, useful in the comparison and processing of subsurface data inferred from well borings. According to geomorphological and pedological considerations, the age of the deposits below the surface (Cremaschi, 1987; Cremaschi & Marchetti, 1995; Marchetti, 1996) is ascribable to the Last Glacial Maximum (LGM). The geomorphological remarks are referred to the relict riverbeds which point to past flow rates greater than the present ones and compatible with glacial feeding.

On this Late Pleistocene surface, relict traces of braiding rivers, at a considerable distance from the Alpine margin, indicate rivers fed by melt water with a highly variable discharge and considerable sediment load. The LGM deposits are characterised on the surface by a pedogenetic cover up to 1 m thick (agw, asw, acw units), testifying to the fact that this surface was exposed during most of the Holocene. It is for-

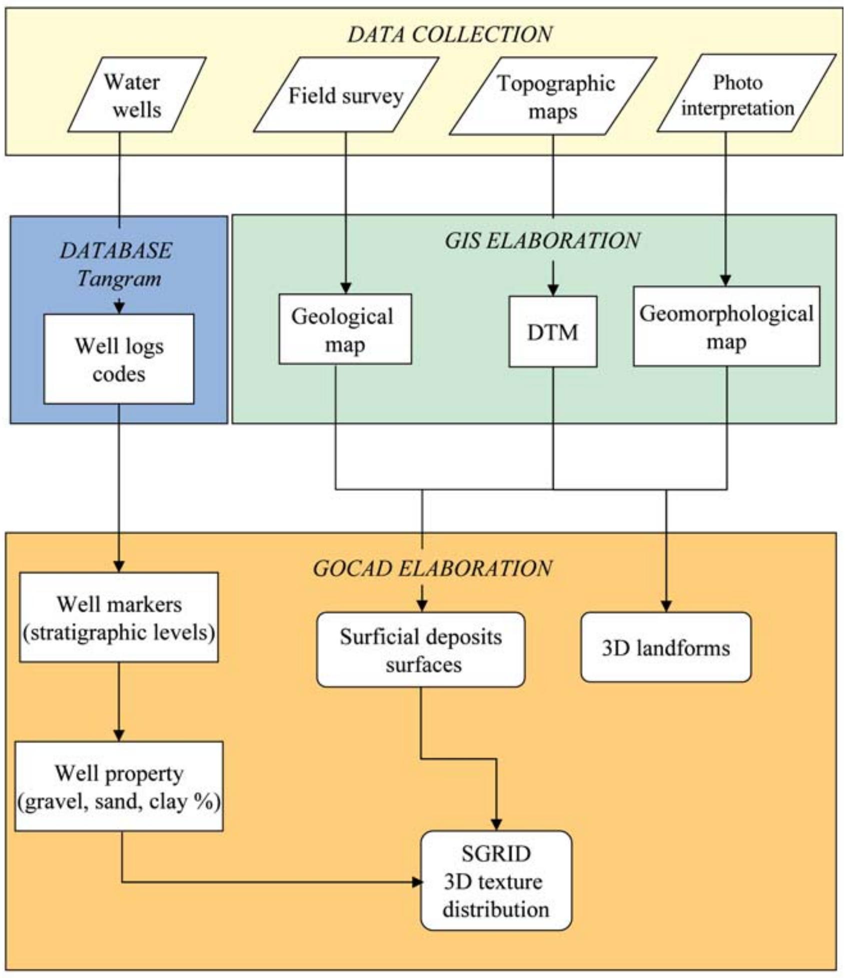


Fig. 3 - *Conceptual model scheme and plates content.*

med of a complex sedimentary body of fluvioglacial and fluvial origin deposited during the pre-Holocene glacial phases.

This surface has indeed preserved the most recent forms of the LGM fluvioglacial and fluvial aggradation phases. Following deglaciation, erosion prevailed and, during the Early Holocene, an intense erosional phase affected all the watercourses of the Alps, forming deeply eroded valleys (MARCHETTI, 1996; CASTIGLIONI *et alii*, 1997).

During deglaciation, erosion formed deep box-shaped valleys, for instance, the Chiese Valley and the Mella Valley as shown in the geomorphological map (Fig. 1). Alluvial deposits in these valley depressions are of moderate thickness, never exceeding a few metres, and always Holocene in age (ag-as-ac units). This sequence of events is found all over the central Po Plain and was reconstructed mainly on the basis of geomorphological investigations. High-stand areas emerge from this wide extension of fluvial and fluvioglacial deposits formed by alluvial materials from both the Late Pleistocene (agw-asw-acw units) and the Holocene (ag-as-ac units). These comprise the outermost moraine reliefs of the Garda (Montichiari-Carpenedolo moraine) and Franciacorta (Rovato area) amphitheatres. These deposits, which have been attributed to glacial expansion phases preceding the LGM (VENZO, 1965; BONI & CASSINIS, 1973; CREMASCHI, 1987), show a weathering layer of over 1 m thickness. Furthermore, these reliefs are partially buried by the younger fluvioglacial deposits of the LGM. In the middle of the map another four areas can be distinguished (Pievedizio, Capriano, Castenedolo, Ciliverghe) in which the weathering cap is more than one metre thick (w-wl units). On the top of the reliefs, a polygenic cover of loess fills and flattens the undulation of the underlying unit (BARONI *et alii*, 1990). The outcropping of the four hills from the outwash plain is related to the neotectonic activity of a buried structure (DESIO, 1966), occurring probably during the Middle Pleistocene (BARONI *et alii*, 1990). The four isolated reliefs have in fact been exposed since at least the Middle Pleistocene, whereas in the easternmost reliefs (Castenedolo and Ciliverghe), units ascribable to the Early Pleistocene also crop out (CREMASCHI, 1987). These reliefs had a structural constraint in the deposition of the LGM alluvial deposits, as testified by widespread traces of braided watercourses south of Bagnolo Mella and south-east of the Castenedolo and Ciliverghe reliefs.

In the Fig. 2 the units represented on the map of Fig. 1 are projected on the Digital Terrain Model (DTM) of the area.

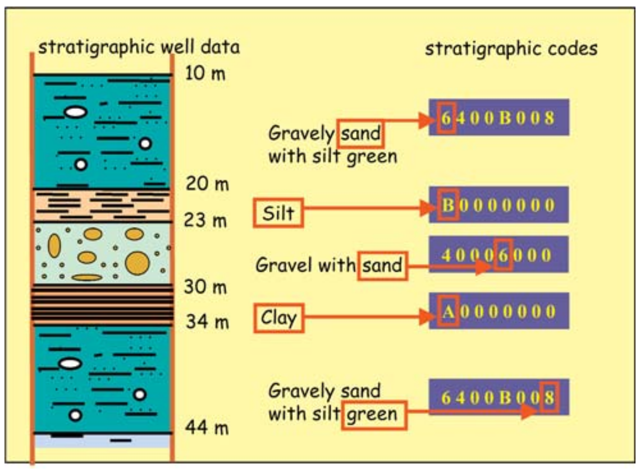


Fig. 4 - *TANGRAM well data base: texture codes.*

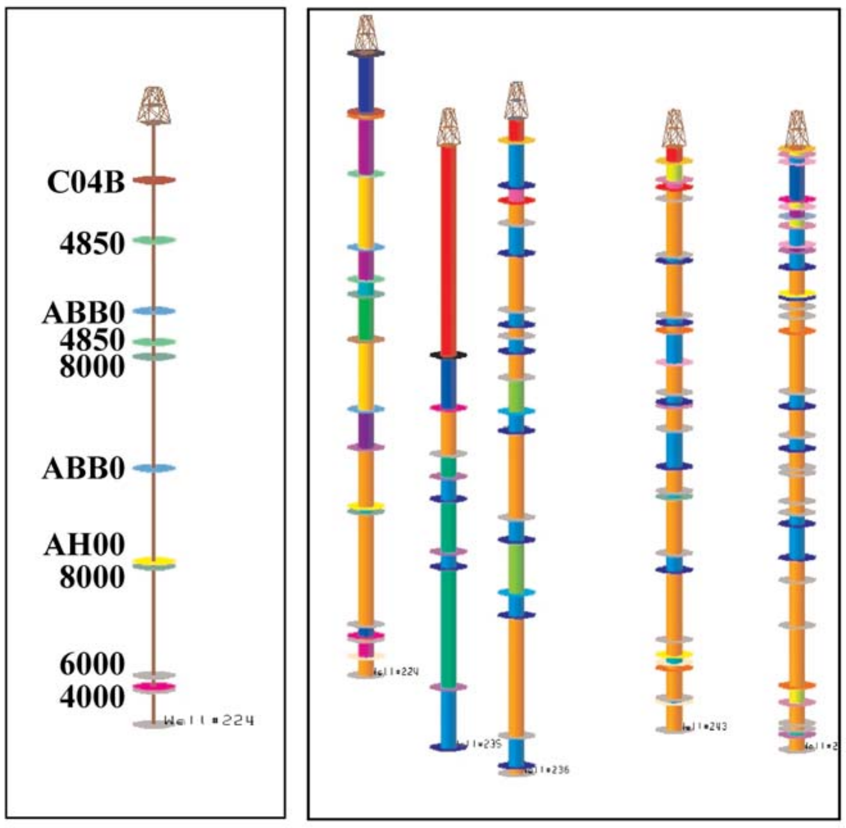


Fig. 5 - *Example of well log translated into a GOCAD Well Object. Left: the markers of the stratigraphic levels (the name is the database code). Right: Well Curve of the porosity in Cylinder format.*

METHODOLOGY

This work shows a 3D reconstruction of the texture distribution of the subsoil of the region of the Brescia plain. The methodology used involved the statistical and three-dimensional (3D) processing (see conceptual model scheme, Fig. 3) of traditional data (geological survey, photointerpretation, topographic maps) organized in data bases (wells data base, geological data base) referred to a GIS (Geographic Information System). The stratigraphic well data are often considered as a simple description of the well logs. They are not usually used in a quantitative way and they are not processed for the purpose of calculating texture distribution. In particular the stratigraphic logs are usually qualitative data, but if a great number of them in an area are stored and coded, their application may become a quantitative use of field information. Many different fields of study require the definition of texture variations for scientific and applied tasks. The recent development of software packages which enable to perform several kinds of operations has improved model data entry from data stored in databases. The creation of the international GOCAD (Geological Object Computer Aided Design) consortium by ASGA (Association Scientifique pour la Geologie et ses Applications, Nancy, France), which has been recently joined by the CNR of Milano (Istituto per la Dinamica dei Processi Ambientali, Sezione di Geologia Ambientale),

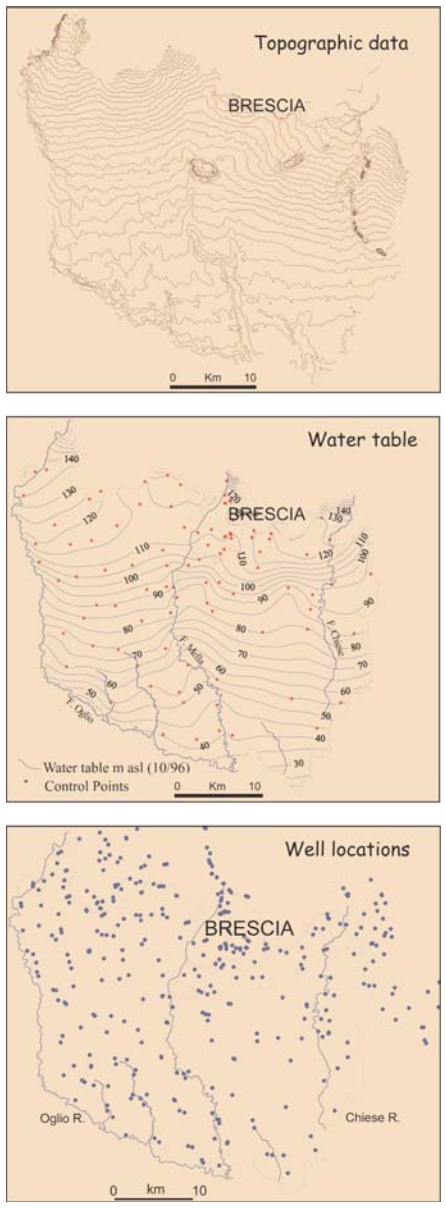


Fig. 6 - *Spatial data (DTM, aquifer bottom and water table) and well locations for the Brescia plain.*

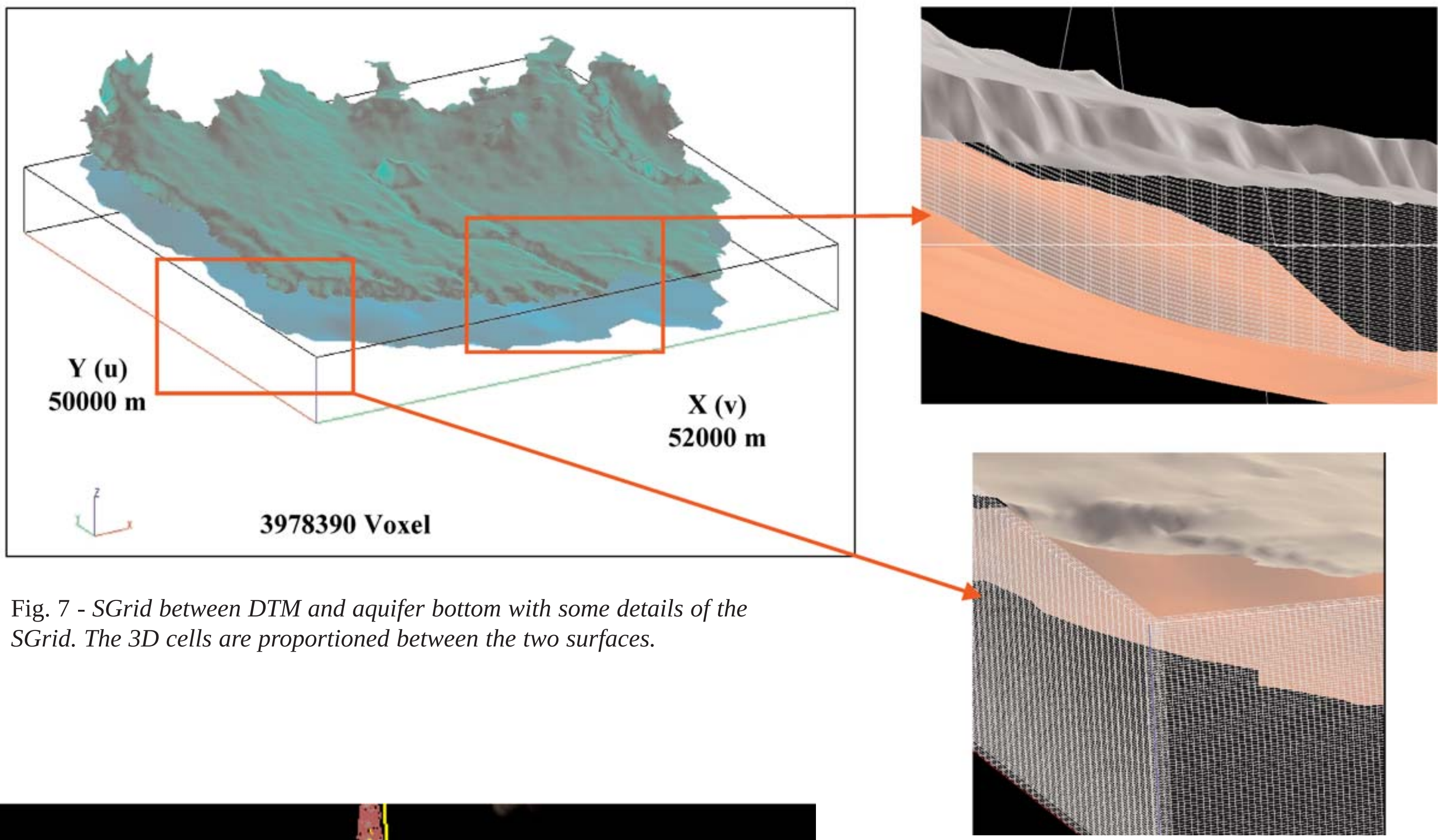


Fig. 7 - *SGrid between DTM and aquifer bottom with some details of the SGrid. The 3D cells are proportioned between the two surfaces.*

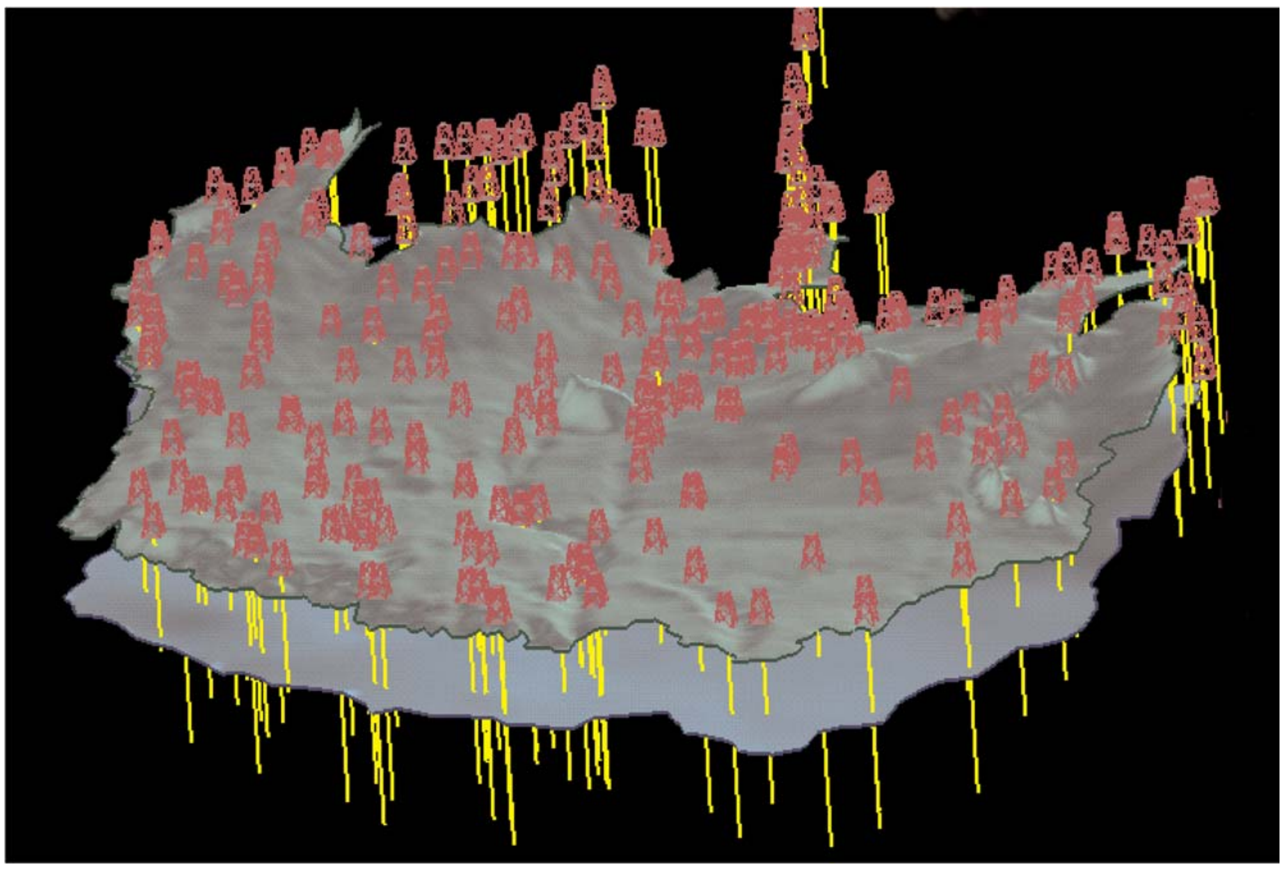


Fig. 8 - *Digital Terrain Model and aquifer bottom surface of the Brescia plain and water wells between them. The yellow lines show the well paths, their length is related to well depth.*

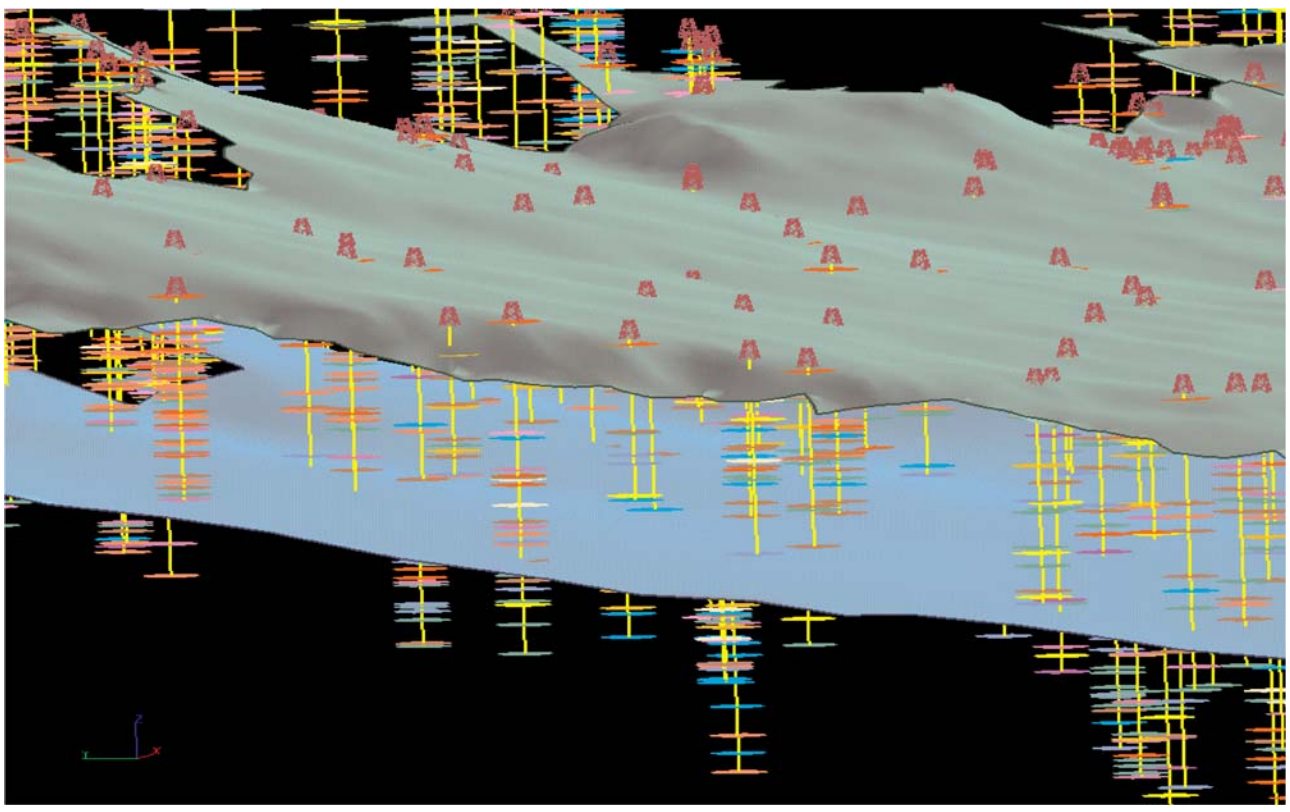


Fig. 9 - *Detail of DTM, aquifer bottom and wells. In each wells stratigraphic markers are represented corresponding to the base of each stratigraphic levels along the well path. These are distinguished by name and colour. Their names are linked to the alphanumeric codes stored in the database, where a same colour corresponds to a same code.*

has strongly improved the use of high-performance 3D software (GOCAD). Using a water-well data base called TANGRAM, developed at the CNR of Milan, well data are stored and their stratigraphic logs are translated into alphanumeric codes. Textural well data can be translated and imported into GOCAD, where a set of 3D special virtual objects is easily constructed. Many surfaces may be imported into GOCAD from a GIS; those shown in the example are the DTM (Digital Terrain Model) and aquifer bottom in the subsoil. Between these two surfaces, a 3D grid (SGrid) is reconstructed with 3D cells (Voxel). The wells are located on a DTM and are defined by marker levels which correspond to different stratigraphic layers. The percent of texture size Gravel, Sand and Silt-Clay is assigned to each stratigraphic layer of the wells. Using the three-dimensional grid, these values are assigned to the nodes of the 3D grid and then processed. In this way the distribution of texture characteristics is calculated on the whole 3D volume of the subsoil (Bonomi *et alii*, 2002).

Well database

The hydrogeological database used is a custom-built package called TANGRAM (Bonomi *et alii*, 1995). This package can be used to store and display all data regarding water wells, including administration, construction, stratigraphic, water-level and hydrochemical details. Its use allows the reconstruction of “layers” and their property distribution and these are the inputs to model in GIS. 415 stored wells are referenced by geographic coordinates and stratigraphic logs. All well logs are translated into codes (Fig. 4). In particular, the definition of each stratigraphic level is converted into 8 alphanumeric figures. These may be divided into two parts: the first part (four characters) refers to the predominant texture (i.e. gravelly sand); the second part (the last four characters) defines the secondary texture (i.e. silty clay). In this way the stratigraphic well data, which are often considered as a simple

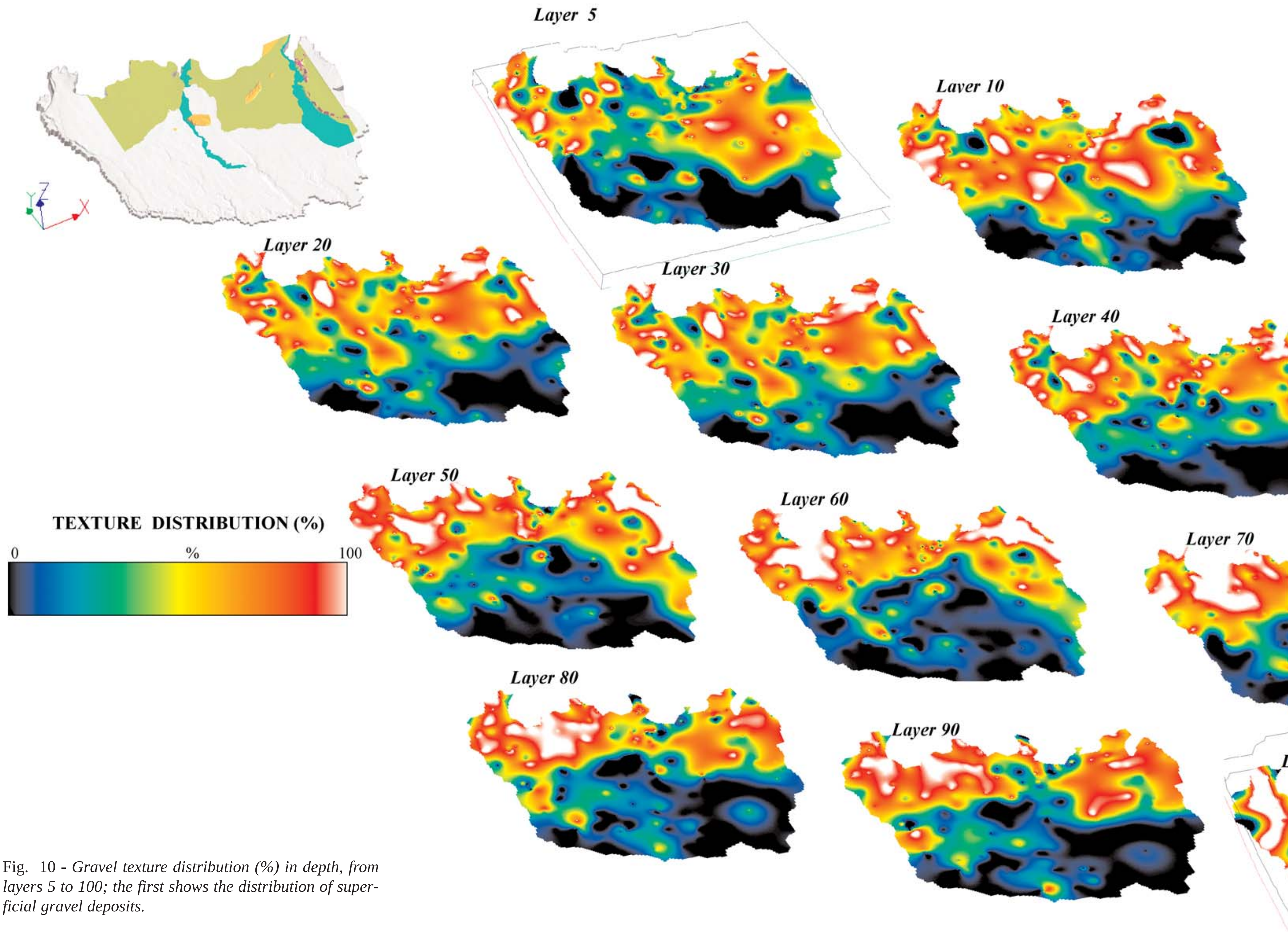


Fig. 10 - *Gravel texture distribution (%) in depth, from layers 5 to 100; the first shows the distribution of superficial gravel deposits.*

description of the well logs, can be quantified and processed.

3D processing

The GOCAD's interpolation engine is the Discrete Smooth Interpolator (DSI) (MALLET, 1992; 1997). The DSI has two built-in objectives: to render elements similar to each other (to smooth) and to change things as little as possible (to remain the same). DSI is an iterative process. The number of iterations it takes to come to a global solution depends on the density (number of Atoms) of the object and on the level of complexity of the constraints.

Textural well data (Fig. 4) can be translated and imported into GOCAD. A conversion program has been developed to translate a "TANGRAM file" into a "GOCAD file". The input is an ASCII file including the well code, the coordinates, the well depth, the textural data etc; the output is a GOCAD well file (Fig. 5). An automatic procedure has been created that can be applied for any other case studies.

The spatial data (DTM, aquifer bottom and water table) from GIS (ILWIS) (VALENZUELA, 1988) (Fig. 6), are converted into a point set Gocad object (VSet), by the conversion program. Also in this case the input is an ASCII file, where each row corresponds to the coordinates and elevation of the grid surface nodes.

The GOCAD Well objects are easily constructed, 3D special virtual objects. They carry location information (Well Path) and property information (Well Logs or Well Curves). Log information in a well is carried in the form of property data points (Fig. 5). These data can be utilised as input for applications and can be displayed along the well path. The number of logs a well can carry is unlimited. Any depths or intervals of significance in a well, such as horizon or fault picks, collection data, etc., can also be included in GOCAD Wells in the form of Well Markers or Well Zones, i.e., each marker can correspond to the bottom of the stratigraphic levels along the path. These differ in name and colour. Their name is linked to the alpha numeric code stored into the database and a same colour corresponds to a same code (fig. 5: i.e. C vegetal soil; 4 sand; 6, gravel; A clay; 9 silt; etc.).

Using the three-dimensional SGrid GOCAD object, the gravel, sand and silt-clay percent values are assigned to the grid nodes. In the SGrid (Fig. 7) the nodes are: 195 along Y(u), 202, along X(v) and 101 along Z(w). The cells are 3,978,390 and each one has a 250 m X 250 m X 1.8 m to 2.3 m width. The SGrid is then modeled between the DTM and the aquifer bottom; the cells are parallel to the bottom aquifer and they are cut in relation to DTM, obviously resulting in a lower number. In this way the texture distribution is calculated on the whole 3D volume of the subsoil. A global view of the DTM, aquifer bottom and wells are shown in the Figs. 8 and 9.

Many 3D sections are analysed to evaluate the gravel, sand and clay distribution: vertical sections parallel to the acquifer bottom, along Z(w), every 10 layers (Fig. 10); N-S sections along X(v) and E-W sections along Y(u) of gravel (Fig. 11) and of sand and clay (Fig. 12).

Statistical processing

The first level of processing of the stored well data consists in a methodology to evaluate texture variations within a layer defined by an upper and a lower surface (DTM and aquifer bottom). In particular, a specific software, linked to the database permits the evaluation of predominant textures within a layer defined between surfaces (e.g. the upper layer being the topography and the lower layer the bottom of the aquifer; BONOMI & CAVALLIN, 1997). This is

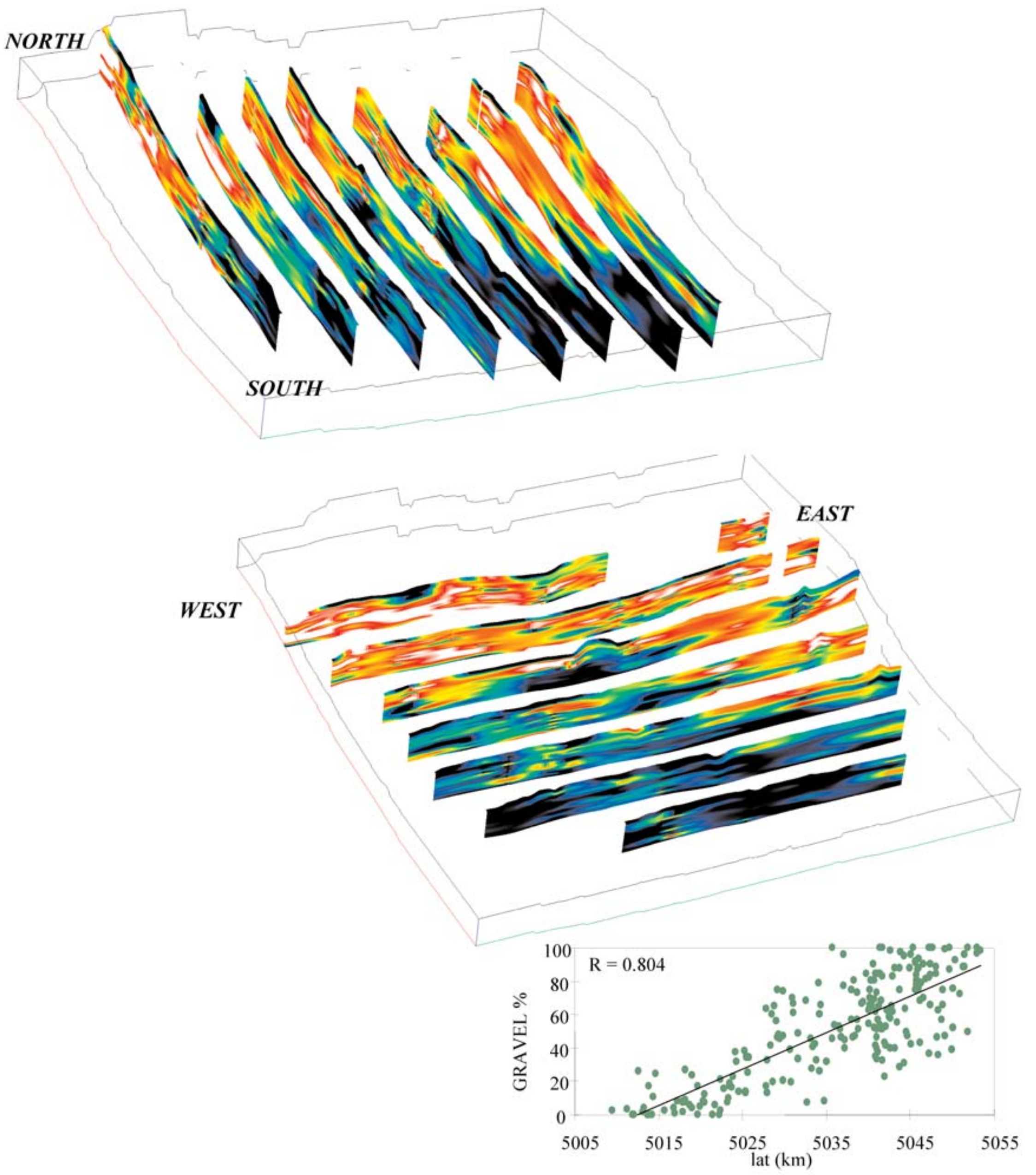
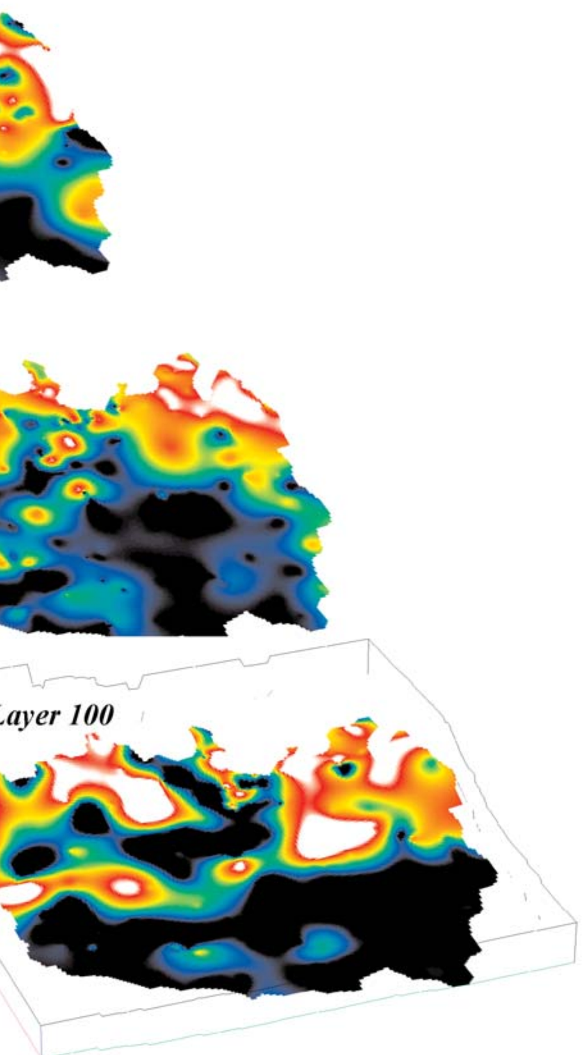
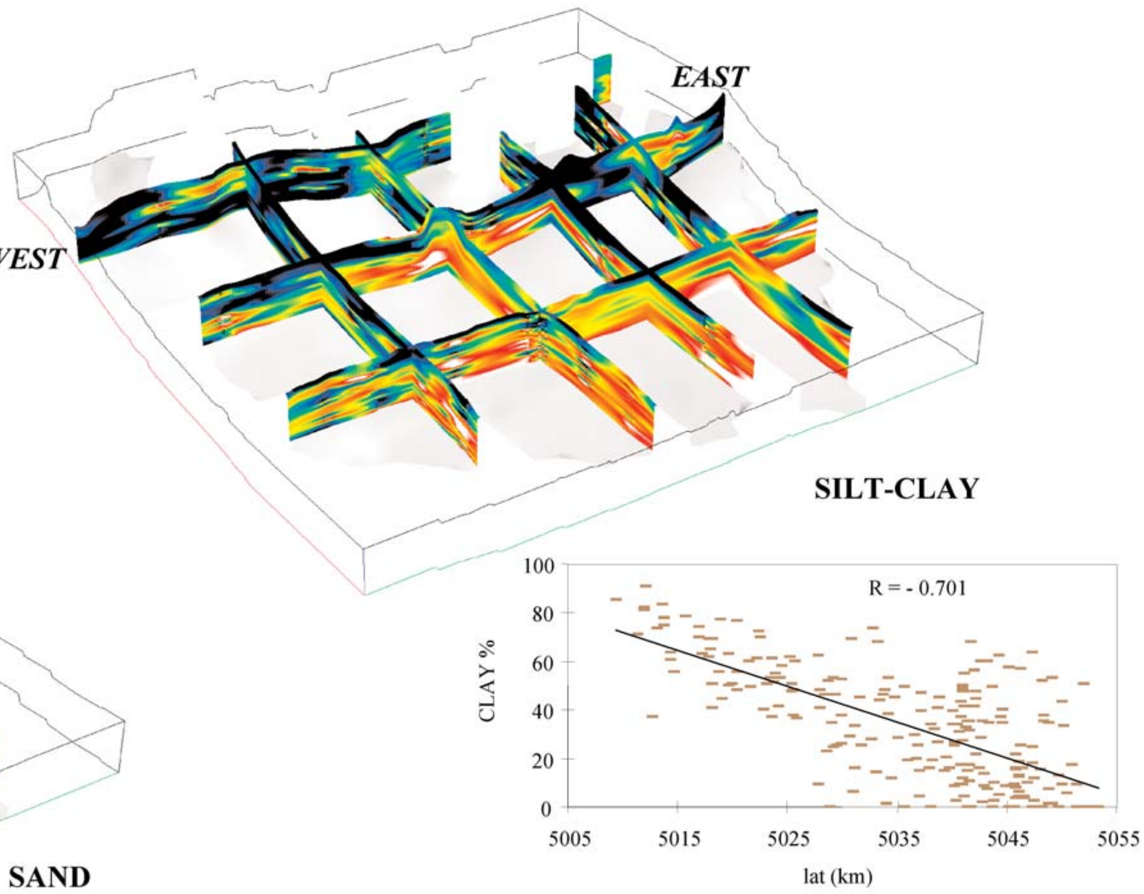


Fig. 11 - *Global view of the N-S and E-W 3D sections of gravel inside the SGrid. For the colour legend see Fig. 10. The lower part shows the correlation between gravel (%) and latitude (km).*





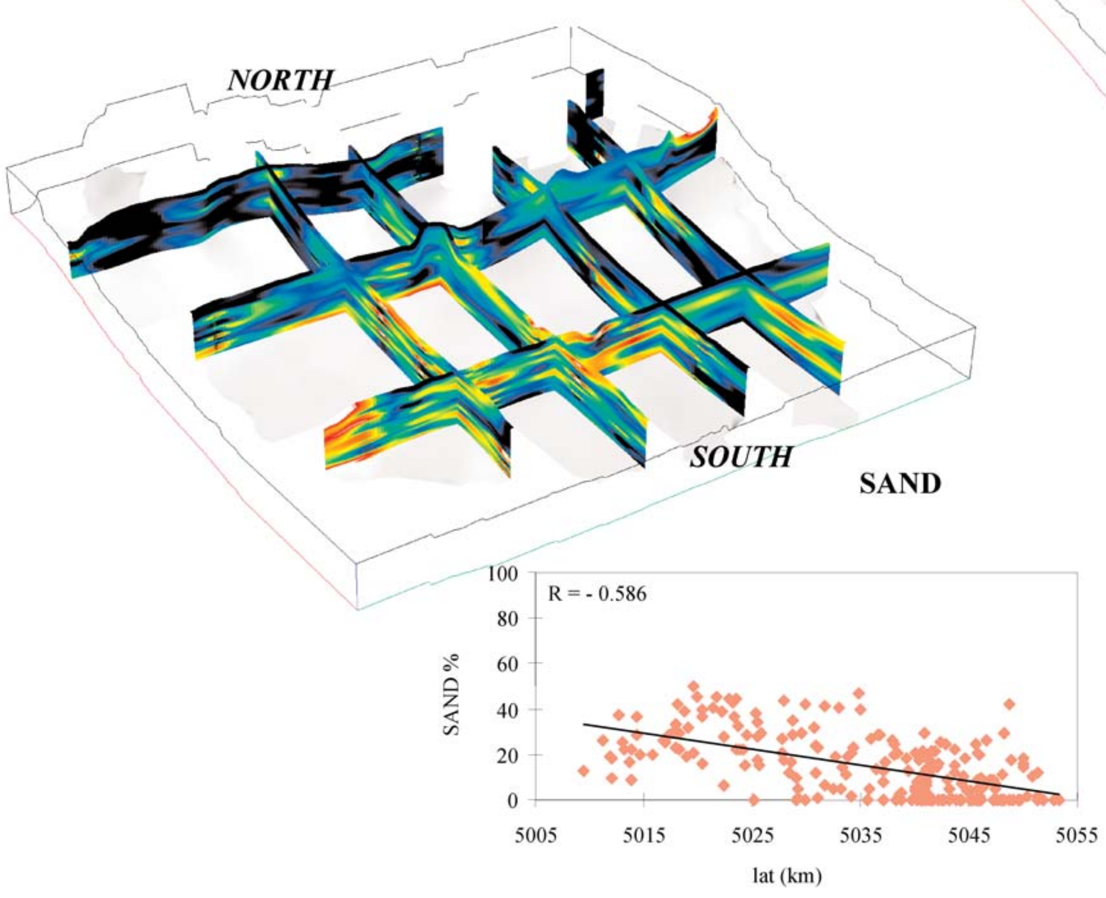


Fig. 12 - *Global view of the 3D cross-sections of the sand (left) and silt-clay (right) in the SGrid. For the colour legend see fig. 10. The lower part shows the correlation between sand and clay (%) and latitude (km).*

done by linking the database to a geostatistic analysis software, within the framework of GIS. Regression analysis is performed on the available stratigraphic logs. Then a number of different factors are defined, such as class intervals, distance, direction and sills. The analysis of these factors permits the quantification of the spatial correlation between measurements at different points and the definition of the particle-size distribution of gravel, sand and clay. In the Brescia area (BONOMI *et alii*, 1997; BONOMI, 1999), gravel increases southward with a positive correlation factor of 0.8 (Fig. 11), sand decreases south-westward with a negative correlation of 0.58 (Fig. 12), and clay also presents a negative correlation of 0.70 (Fig. 12).

CONCLUDING REMARKS

Statistical processing of the textural data may be conveniently utilised to interpret the main sedimentation and erosion events on the basis of geomorphological surface studies. In fig. 10, a sequence of textures is shown with decreasing levels with respect to the ground surface. Here the different colours represent the gravel percentages (from 0% shown by cold shades and dark colours, up to 100% shown by warm shades and maximum brightness). The observation of these block diagrams, together with the series of sections (representation of the three blocks in which the percentages of gravel, sand and silt-clay are shown) and the former block showing the main forms and the surface gravel textures, allow the formulation of a number of considerations. First of all, the presence of two distinct gravelly bodies at surface is quite evident; in the north-western sector their provenance is correlated to a series of dischargers of the Iseo moraine amphitheatre, whereas in the north-eastern sector the provenance of the depositional bodies is better defined, laterally controlled by the Montichiari moraine arc and the isolated ridges of Ciliverghe and Castenedolo (Garda MA). The provenance of coarser sediments from the two glacial systems seems to dwindle in the deeper levels, whereas well-distributed gravelly and also sandy sediments, arranged according to the general dip of the whole upper Po Plain, are present. This distribution might therefore suggest a different genesis and provenance of the most superficial sediments with respect to the immediately underlying ones. While the most superficial deposits are in some way related to glacial systems, the deeper ones could have had a proper fluvial origin. These two first hypotheses, which require further evidence, enable an appreciation of the potentialities of this method. Indeed, if adequately supported by additional information concerning the age of the deposits and the petrographic features of the sedimentary bodies, this method could contribute effectively to the space-time reconstruction of the principal aggradation bodies of the whole Po Plain.

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