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A seamless database for a digital geological map of central Italy: the case of Emilia-Romagna, Marche, Tuscany and Umbria regions

Altair Pirro (a), Paolo Conti (b,c), Gianluca Cornamusini (b, c), Luigi Carmignani (b, c), Giulia Verdiani (b), Bernadette Meola (b), Guido Lavorini (d), Andrea Motti (e), Marco Pizziolo (f), Claudia Bettucci (g), Giovanna Daniele (f) & Norman Natali (e)

- (g) Regione Emilia, Servizio Geologico e Geologico e dei Suoli, Bologna.
 (g) Regione Marche, Servizio Infrastrutture Trasporti ed Energia, P.F. Urbanistica, Paesaggio e Informazioni Territoriali, Ancona.
- Corresponding author e-mail: pirro@cgt-spinoff.it.

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ABSTRACT

In 2012, the Emilia-Romagna, Marche, Tuscany and Umbria regions signed a Memorandum of Understanding for the development of a geological map of their territories. Based on previous results, a unique geological database has been produced with a geographic mapping in GIS vector format at a scale of 1:10,000. The emergence of inconsistencies in initial cartography made necessary the revision of four pilot areas: "Conca-Marecchia", "Tuscany-Umbria", "Pistoia-Modena" and "Massa Carrara-Parma". With regards to the latter, the problems to be solved were: a) the position and correlation between tertiary turbid arenaic formations; b) interpretation of the position of marvelous sequences; c) interpretation of the tectonic structures of the Passo del Cerreto- F.Secchia, with outgrowth of medium-grade metamorphic rocks tectonically juxtaposed to evaporitic triassic formations; d) the nature and age of the tectonic contacts at the roof of the succession of the Passo del Cerreto-F.Secchia and of the area of the M.Ventasso. To solve some critical issues, field data have been integrated with information about the age of the stratigraphic successions mentioned above, through biostratigraphic and petrographic studies. The final product consisted in a new database useful to test the geological data concerning some critical revision areas.

KEY WORDS: geodatabase, GIS, seamless dataset, largescale geological map.

INTRODUCTION

In recent years, the Emilia-Romagna, Marche, Tuscany and Umbria regions have independently completed geological mapping at a scale of 1:10,000 within their respective administrative territories and have made it freely available through their geological service websites. Geological maps are the result of surveys performed by universities, institutes of the National Research Council, public and private entities, freelance geologists. In some cases, the geological surveys were part of the CARG (Geological CARtography) Project, which aimed at creating geological and geothematic sheets on a scale of 1:50,000 over the entire national area. The CARG project was carried out by the Italian Geological Survey of Italy-ISPRA.

The cartography produced, while covering the area of the four regions, shows various inconsistencies, and above all:

a) different names of geological formations are often used to indicate the usual lithostratigraphic unit;

b) different rocks are sometimes identified with the same name (as a result of different interpretations of geologic successions and tectonic arrangement of an area);

c) some areas have legends for quaternary units based on different stratigraphic principles (e.g., legends based on Unconformity Bounded Stratigraphic Units - UBSU, (Chang, 1975) and legends based on classic ubiquitous stratigraphic units, such as floods, slopes (Bonciani et al., 2012) etc.

In order to achieve a common map of the four regions, the following problems also have to be solved:

- lack of a homogeneous geological legend for the four regions, structured in paleogeographical domains, tectonic units, etc (Bigi et al., 1990);
- lack of a geological database structure valid for all regions, so that all geological information can be processed in a GIS environment and disseminated with a shared data structure;
- "junction" problems at the administrative boundaries, i.e., the common boundaries to the single geological cartographies;
- homogenization of the types of tectonic contacts occurring.

MATERIALS AND METHODS

Following the definition of the Preliminary Geological Legend (Verdiani et al., 2014) applicable to the interregional territory, a database was designed (Fig. 1) with the aim of storing all the existing geological data for the four regions. In order to integrate all the available data, it was decided

⁽a) GeoExplorer Impresa Sociale s.r.l., Via Vetri Vecchi, 34, 52027 San Giovanni Valdarno, Italy. Tel: +39 055-9119428 - Fax: +39 055-9119439.

⁽a) GeoLapiorer Impress obstation view of the control of (e) Regione Umbria, Servizio Geologico e Sismico, Perugia.



Fig. 1 - New Geological Interregional Database scheme not yet adherent to the GeoSciML model, undergoing experimentation.

to develop a database that would reflect as much as possible the data structure of the database of the Seamless Geological Database of the Tuscany Region (BDG-RT) (Pirro et al., 2012) at 1:10,000 scale.

This database, developed by the Centre for Geotechnologies of the University of Siena, presents an object-oriented relational structure aimed at managing and storing large amounts of geological and geothematic information. Processing of existing data for data entry and thematic homogenization was fundamental in the design and implementation of the database. The most of geospatial elaborations were performed in ESRI TM ArcGIS® Desktop 10.5 (ESRI, 2015) environment, often by manual editing. In this new structure we took into account the new types of data (e.g., new types of geological limits, etc.) to be stored in the database, considering also the relationships between the geological formations at the 1:100,000 scale and those at the 1:250,000 scale.

On the other hand, updating of data structure to the GeoSciML model (IUGS CGI, 2008) is in progress in order to comply with the INSPIRE directive (European Commission, 2007). In addition, a unique geological map at a scale of 1:250,000, similar to Geological Map of Tuscany (Carmignani et al., 2012; 2013), is currently under construction.

REVISION AREAS

To overcome the issues mentioned in the Introduction and to produce a "continuous" geological mapping in GIS vector format, the four regions have decided to solve the boundaries problems by instructing the Center for GeoTechnologies of the University of Siena to consider four critical pilot areas which are representative of the issues to be faced:

- a) the basin of the Conca-Marecchia rivers ("Marecchia" area in Fig. 2, Emilia-Romagna, Marche, and Tuscany regions);
- b) the area located at the administrative boundary between the Tuscany Region and the Umbria Region ("Toscana-Umbria" area in Fig. 2);
- c) the area of the Tuscan-Emilian Apennines across the provinces of Pistoia and Modena ("Pistoia-Modena" area in Fig. 2);
- d) the area of the Tuscan-Emilian Apennines at the border between the provinces of Massa-Carrara, Lucca, Parma and Modena ("Massa Carrara-Parma" area in Fig. 2).

Each of these areas exhibits geological peculiarities that require analysis and aggregation of different litostratigraphic units (quaternary formations and deposits). The work done for each area is described below. It is important to remember that no field observations or new stratigraphic data have been collected, and this work of data homogenization has been carried out on the basis of accurate analysis of the existing geological cartography and literature.



Fig. 2 - Location of the four study areas, blue lines indicate the regional boundaries. Continuum Central Italy geological base map at a scale of 1:250.00 under completion and publication.

CONCA-MARECCHIA AREA

The Basin of the Conca and Marecchia rivers includes administrative territories in the regions of Emilia-Romagna, Marche, Tuscany, including the Republic of San Marino. The use of different databases, carried out by different entities and at different times (Fig. 3), necessarily involved problems of "attaching" among them. Where the geological coverage of the five databases comes into contact, various types of inconsistencies have been found. More in detail, in the five databases: a) polygons that come into contact sometimes have different informative



Fig. 3 - Geological databases available and used for the geological map of the Conca-Marecchia basin area. The boundary of the basin area is indicated in blue, the regional boundaries are indicated in red.

attributes; b) limits with different attributes of contacts occur (e.g., direct faults that continue as overcrowding in the adjacent database); c) different names are used to indicate the usual rock type; d) different types of rocks are identified with the same name; e) geometric attaching problems between polygons exist.

Some examples of these inconsistencies and attaching problems are shown in Fig. 4.

From the geological point of view, it was necessary to reorganize the different geological formations in sedimentary successions and tectonic units. Characterization and interpretation of the so-called Coltre della Val Marecchia (Cornamusini et al., 2017) represented the most problematic aspect. At the end of the work, a continuous geological mapping was produced for the whole area at a scale of 1:10,000. For this area, all produced documents and cartographies are freely downloadable in SHP vector format (shapefile) from the web site: www. geotecnologie.unisi.it/marecchia.

TUSCANY-UMBRIA BORDER AREA

The area along the Tuscany-Umbria regional boundary was subsequently studied (Fig. 2). To solve the problems of junctions between the two geological databases (Pirro et al., 2012; Regione Umbria, 2012), it was necessary to standardize the lithostratigraphy of recent deposits. The Geological Map of the Umbria Region on a 1:10,000 scale (Regione Umbria, 2012) has a Plio-Plestocene and Quaternary succession divided into symmetries and supersymmetries (Synergy of Allerona, Sintema of Citerna, Sintema of Fighille, Sintema of Monterchi, Tiberinus Supersynthesis, etc.). To allow correlation of these deposits with similar successions emerging in the adjacent regions, they were subdivided into sequences such as Pliocene Marine Deposits, Pleistocene Marine Deposits, Woolfranchian Continental Deposits, and Medium-Upper Pleistocene Deposits. Concerning the Falda Toscana succession, some changes to the legend were related to tertiary turbidity successions: outcropping of the Macigno formation (divided into several members) was correlated and assigned to Falterona's sandstone formation (with its members), while the underlying clayey succession was related to the formation of the Marne de Villore. At the end of the work, a continuous geological mapping was carried out throughout the area at a scale of 1:10,000.

For this area, all the produced documents and cartographies are freely downloadable in SHP vector format (shapefile) from the web site: www.geotecnologie. unisi.it/toscana-umbria

NORTHERN APENNINES AREA (PISTOIA-MODENA PROVINCE)

In the northern Apennines (Boccaletti & Coli, 1982), an area along the border of the Tuscany and Emilia Romagna regions, in the provinces of Pistoia and Modena (Fig. 2), has been studied. Other elaborations concerned the succession overlying the Tuscan units, and finally the modification of the Ligurian units. We point out the important contribution of the geologists of the Berlin School (Reutter et al., 1991), the school of Pisa (Plesi, 2002; Botti et al., 2009), the school of Florence (Bruni et



Fig. 4 - Problems of attaching between the 1:10,000 cartography of the Emilia-Romagna Region (top) and the Tuscany Region (bottom) in the West of Sasso di Simone area, drawn in the yellow rectangle in Fig. 2 The blue line is the regional limit. Critical areas are bounded by ellipses.

al., 1994a; b) and the Universities of Parma and Modena-Reggio Emilia (Bettelli et al., 2002; Vescovi, 2005). Recently, some authors provided an important contribution in interpreting the succession overlying the Tuscan unit (Sestola-Vidiciatico Unit), which is considered to be a tectonic unit with high internal deformation (cutting area) that would represent the original limit of plates between the Ligurian and continental Tuscan ocean units (Remitti et al., 2011; 2012). The area includes the successions of Falda Toscana, M. Modino and M. Cervarola, which went through different interpretations regarding their age, geometric relationships and original paleogeographic position. These interpretations, often very different from each other, are well summarized by Chicchi & Plesi (1991). If compared with the existing cartography (regional geological databases), the cartography produced in this project has also the mission to highlight the introduction of the Sestola-Vidiciatico Unit. This tectonic unit consists of flakes and elements coming from various formations of the Ligurian and Tuscan units (Vannucchi et al., 2008; Remitti et al., 2007); in the cartography produced, some polygons of Ligurian or Tuscan formations (e.g., Arenarie di M. Modino) were attributed to the Sestola-Vidiciatico Unit. In addition, for this area all produced documents and cartographies are freely downloadable in SHP vector format (shapefile) from the web page: <u>www.geotecnologie.</u> unisi.it/Pistoia-Modena.

NORTHERN APPENNINE AREA (MASSA CARRARA-PARMA PROVINCE)

In the northern Apennines, an area along the border between Tuscany and Emilia Romagna regions has been considered. This includes parts of the provinces of Massa-Carrara and Parma (Fig. 2), and to a lesser extent the provinces of Lucca and Reggio Emilia. Field activities and cartography were completed at the end of 2016. In addition to the common problems of junction between different geological databases in this area, major issues concerned: a) the position and correlation between the tertiary turbid arenaceous formations (Macigno, Arenarie di M. Cervarola, Arenarie di Pracchiola); b) interpretation of marvelous sequences (e.g., Marne di Marra) as a stratigraphic formation overlying the Tuscan succession or as tectonic flakes within the complex structure of subligural units in this area; c) interpretation of the tectonic structure of the Passo del Cerreto-Valle Valley of F. Secchia, with outcrops of medium-degree metamorphic rocks tectonically juxtaposed to evaporitic triassic formations; d) the nature and age of tectonic contacts above the Cerreto-F Pass. Secchia and the area of M. Ventasso. For some of these geological problems, it was necessary to supplement the field activities with information on the age of these successions.

DISCUSSION AND CONCLUSIONS

Proper handling and processing of geological data are key aspects for planning, protecting and mitigating the natural risks in any area. For an integrated and efficient approach to spatial planning, the availability of constantly updated geological data, which are interoperable and manageable by a GIS platform, is necessary for both local and national administrations, and also for the scientific community. The efficient and qualified management of hydrological, geothermal and natural resources and studies are dealing with risk prevention. All information needs to be based on a correct and detailed knowledge of the geological aspects of the territory.

The test of the seamless geological interregional database, presented in this work, store data from such prototype area. This area is believed to be representative with regards to its location and the variety of geological coverages, originally contained in the databases provided by each region. The main contribution of this database is the spatial continuity of contents, realized through the harmonization of existing geological data sets of Emilia Romagna, Marche, Umbria and Tuscany regions. An important application on the seamless database was then the reorganization of the information related to the geological substrate, quaternary deposits and landslides. The storage of information about landslides and quaternary deposits in the new database structure (different from that used in the CARG project) and the chance to recover geological contacts among deposits allowed to create a Geological Map of the bedrock. Furthermore, this data structure can provide a more direct approach to instability phenomena, as well as a targeted updating of the geological bedrock and quaternary coverings.

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