Chapter 15: 3D Geological Modelling at the Geological Survey of Italy (Servizio Geologico d’Italia): an Overview

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Introduction

Since 2000 geological 3D modelling is part of the institutional mandate of the Servizio Geologico d’Italia (SGI). In a country characterized by high geological complexity, natural hazards (e.g., earthquake, volcanic activity) and increasing demand of natural resources, several 3D models have been produced to answer the need for a better knowledge of subsurface geology. These activities have been carried out in the framework of national and European projects. The SGI has also devoted significant efforts to the design of specific workflows both for the 3D model building stage and the following analysis and applications.

Despite the important progress, several aspects remain unresolved: the poor use of 3D geological models by a large number of stakeholders, probably related to the dissemination format of 3D models; and the extension to the entire Italian territory of a “bedrock and Quaternary 3D model” thus providing a framework for detailed local 3D geological models.

Organizational Structure and Business Model

The Servizio Geologico d’Italia (SGI) is the national geological survey for Italy; it was established in 1873 and since 2008 it became a Department of the larger Italian Institute for Environmental Protection and Research (ISPRA). Its institutional mandate has progressively expanded coupling geological and geothematic mapping with technical-scientific support to local, regional and national authorities in several fields of the geosciences (e.g., natural hazards, hydrogeology, monitoring of soil and subsoil conditions, geophysics). In case of emergencies (e.g., earthquakes, landslides, floods) the SGI acts as an operational arm of the Italian Civil Protection Service and also provides scientific and technical support in seismic microzonation studies. Its production at various scales of geologic and geothematic national coverages (from 1:1,000,000 to 1:50,000), and relevant database, provides a complete collection of geological information of the Italian territory. Since 2000 SGI has embraced 3D geological modelling to implement analysis and visualization of geoscience data; this activity is supported mainly by European (EU) funds to research and applied sciences, or realized for national research projects.

The SGI maintains a staff of 140 people, composed by 120 technical and 20 administrative units. The annual budget is about 1 million Euros; more than the 50% of the budget derives from European or national project-related funding.

In February 2019 a “Work Group on 3D geological modelling” has been established based on the cooperation between SGI and 8 regional GSOs, with the main aims to exchange knowledge, workflows, and tools, and to define national standards for production, exchange, and dissemination.

Overview of 3D Modelling Activities

The geological 3D modelling activities carried out by SGI have as a main goal the maximization of the geological information through the integration of surface and subsurface data derived mainly from SGI national geological databases, to support applicative uses or tectonostratigraphic analyses. Several 3D geological models, from local to nation-wide coverage, have been built to describe various geological domains, from fold-and-thrust mountain belts to plain areas (Figure 1); they are part of “GeoIT3D - 3D modelling and visualization of geological data” institutional framework.

Initially, 3D models built by SGI were related to the National 1:50,000 scale Geological Mapping Project (CARG Project). The idea was to pair the geological mapping with a 3D model of the geological complexity in the subsurface. These 3D models, covering the area of a single Geological Sheet at 1:50,000 scale (~600 km^2), were mainly based on field data (e.g. stratigraphic boundaries, attitudes, tectonics), geological cross-sections, and borehole stratigraphies obtained from the CARG Project database (1:25,000 scale), integrated with seismic reflection profiles, if available. The quality of the resulting 3D models demonstrated the full applicability of SGI public geological databases to obtain comprehensive and coherent 3D models in different geological domains such as the Apennines thrust belt (Fossombrone Sheet, Figure 2A)

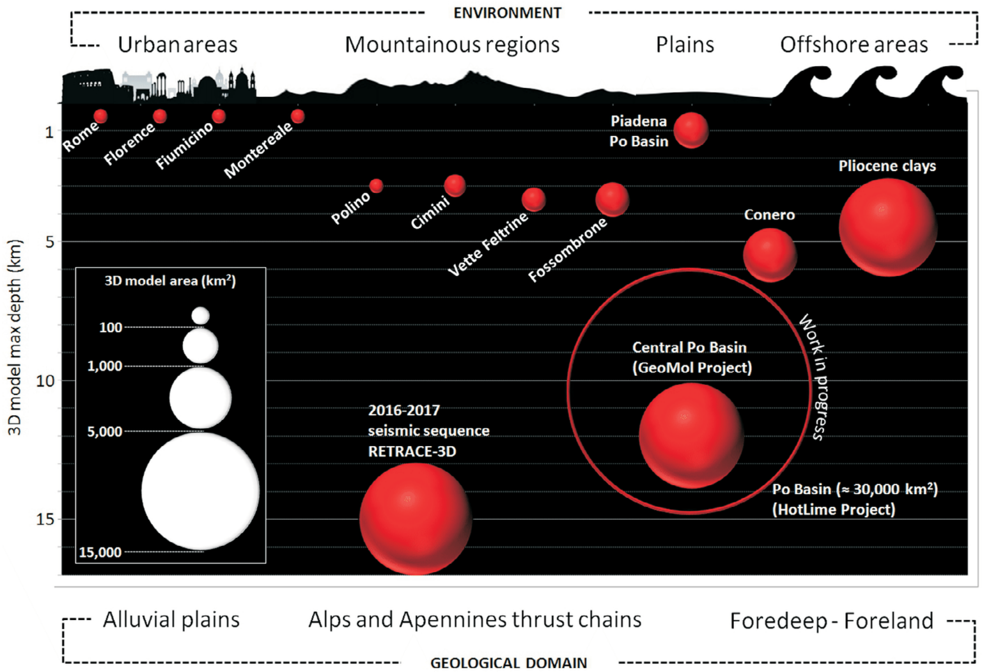

Figure 1. 3D geological models produced by SGI in the frame of "GeoIT3D - 3D modelling and visualization of geological data", supported by EU or national funds. See Figure 3 for the location of each model.

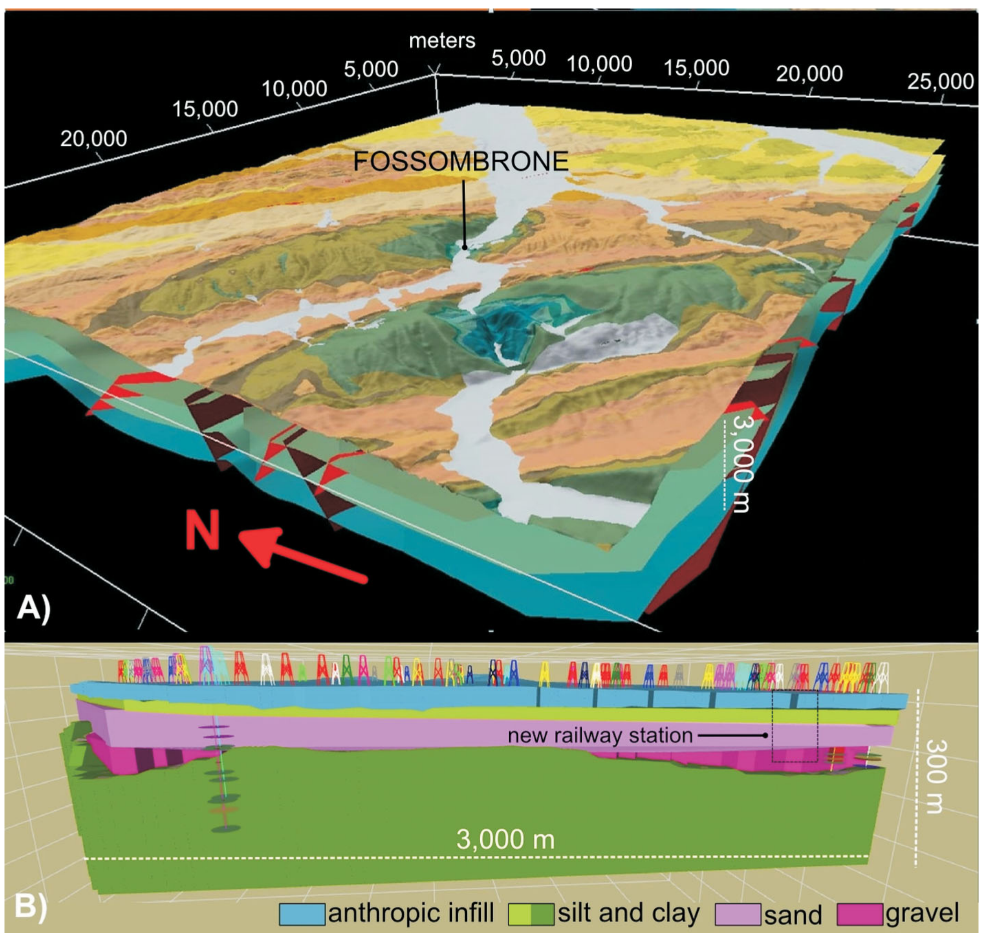

Figure 2. A) 3D geological model of the Geological Sheet Fossombrone; **B)** 3D geological model of the urban area of Florence, view from north. See Figure 3 for the location.

(De Donatis et al. 2002 and D'Ambrogi et al. 2004) or alluvial-coastal areas (Fiumicino Sheet, see Figure 3 for the location).

Following this experience, the SGI 3D modelling activities have been expanded in two domains. Firstly to specific projects dealing with applicative purposes (e.g. tunneling, hydrogeology, geothermal studies), urban geology, basin analysis, and seismotectonic studies. Secondly to long-term activity devoted to the production of a 3D framework for the entire Italian territory.

Small and shallow 3D models of the urban areas of Rome and Florence (1 and 2 in Figure 3) were almost exclusively realized based on borehole stratigraphies, with some additional data derived from surface geology. These models investigated to a few hundred meters depth the subsurface, giving a well-constrained description of the geometrical relationship of the units within alluvial sediments (e.g., Florence area), or thickness of anthropic infill (e.g., Rome), and underlying volcanic units. The 3D model of the Florence urban area (Figure 2B) was realized in the framework of the Environmental Observatory, defined by the Italian Ministry of Environment, for a new underground railway station. It allowed the calculation of the volume of coarse alluvial sediments intercepted by the underground excavation and supported relevant decisions on the disposal of the excavated material, including its potential recycle as natural aggregate for concrete.

In the Alps and Apennines, small regions covering a few hundred km^2 have been modelled, in collaboration with universities, as part of scientific projects for paleogeographic and structural analyses: i) the evolution of a Jurassic Pelagic Carbonate Platform (Polino area, 4 in Figure 3), ii) the shortening of a sector of Southern Alps (Vette Feltrine - 6 in Figure 3; D'Ambrogi and Doglioni 2008), iii) the evolution of thrust-related anticlines, with quantitative evaluation of uplift rates and Plio-Pleistocene sedimentary infill (Piadena - Po Basin, 8 in Figure 3; Maesano and D'Ambrogi 2016), iv) the Quaternary basin infill history of a tectonically controlled intermontane basin (Montereale, 3 in Figure 3; Chiarini et al. 2014).

Geological 3D models of larger areas (1,500 - 15,000 km^2) have been completed as part of European funded projects for resources assessment or national research programs supporting quantitative analysis of faults activity related to seismogenic potential evaluation (Central Po Basin, 8 in Figure 3: Maesano et al. 2015, Maesano and D'Ambrogi 2016; Conero, 9 in Figure 3: Maesano et al. 2013). These 3D geological models extend to a depth of up to ≈20 km by integrating seismic reflection profiles, deep wells for hydrocarbon and geothermal exploration, and other data (e.g., instrumental seismicity, gravity and magnetic anomalies, heat flow).

The 3D geological model of the central Po Basin (Figure 4), produced in the frame of the European funded project GeoMol "*Assessing subsurface potential of the Alpine Foreland Basins for sustainable planning and use of natural resources*", covers an area of 5,700 km^2 and reaches a depth of 12 km (GeoMol Team 2015; ISPRA 2015). This model will be extended to the entire Po Basin, a plains area of more than 30,000 km^2, in the upcoming HotLime - GeoERA Project (*Mapping and Assessment of Geothermal Plays in Deep Carbonate Rocks – Cross-domain Implications and Impacts*) (12 in Figure 3).

Since 2009 the SGI 3D models production has focused on active tectonics and seismogenic faults; the areas hit by the most recent seismic events were modelled with special attention to the geometry and relationship between faults. A further step will be the collection of geometrical data derived from the existing 3D models as the contribution to the European Fault Database that will be realized in the HIKE - GeoERA Project (*Hazard and Impact Knowledge for Europe*).

Currently, the National Civil Protection Department supports the collaboration between SGI and other research institutes for producing the 3D crustal model of the area hit by 2016/2017 Central Italy seismic sequence (max Mw 6.5, and four events of Mw >5.0). This 3D model will be realized in the project RETRACE-3D "Central Italy Earthquakes Integrated Crustal Model" (www.retrace3d.it), that has also the support of private oil companies (ENI and TOTAL), that kindly provided the seismic reflection profiles of a large area (>5,000 km^2, 10 in Figure 3).

The next long-term step will be the building of an Italian Bedrock and Quaternary 3D model, through the full integration of the data stored in SGI databases and local 3D models, with data from external sources (Figure 5). A preliminary harmonization phase of basic datasets is ongoing and will hopefully be implemented by the collaboration with regional geological survey organizations and other research institutes. This long-term challenging activity started in 2010 (D'Ambrogi et al. 2010) with a first 3D visualization of the crustal and sub-crustal structure of Italy, including main seismogenic sources, seismicity distribution, Moho discontinuity, and lithosphere-asthenosphere system.

Resources Allocated to 3D Modelling Activities

The annual resources allocated to 3D modelling activities at SGI vary significantly from year to year as they derive mainly from the participation to nationally-, European-funded research and applied-science projects. These project-related resources clearly constrain the 3D modelling activities either for choosing the areas to be investigated or for selecting the

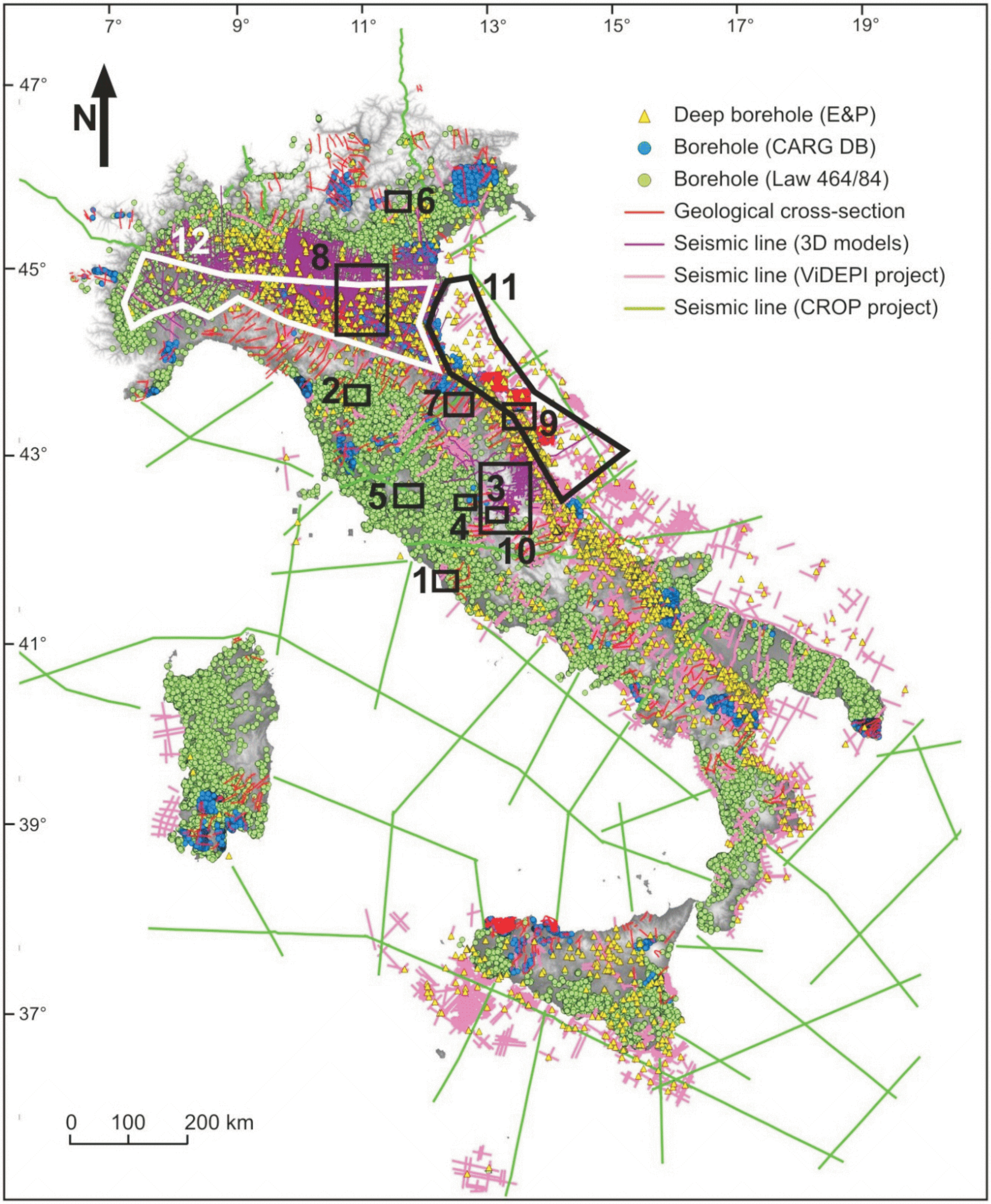

Figure 3. Distribution of main geological data publicly available. Purple lines indicate seismic lines used for 3D model construction available under a confidentiality agreement. Black polygons indicate the areas covered by 3D models, in white those under construction. 1. Rome and Fiumicino, 2. Florence, 3. Montereale, 4. Polino, 5. Cimini, 6. Vette Feltrine, 7. Fossombrone, 8. Po Basin: GeoMol Project and Piadena, 9. Conero, 10. RETRACE-3D Project area, 11. Pliocene clays, 12. Po Basin: HotLime Project area.

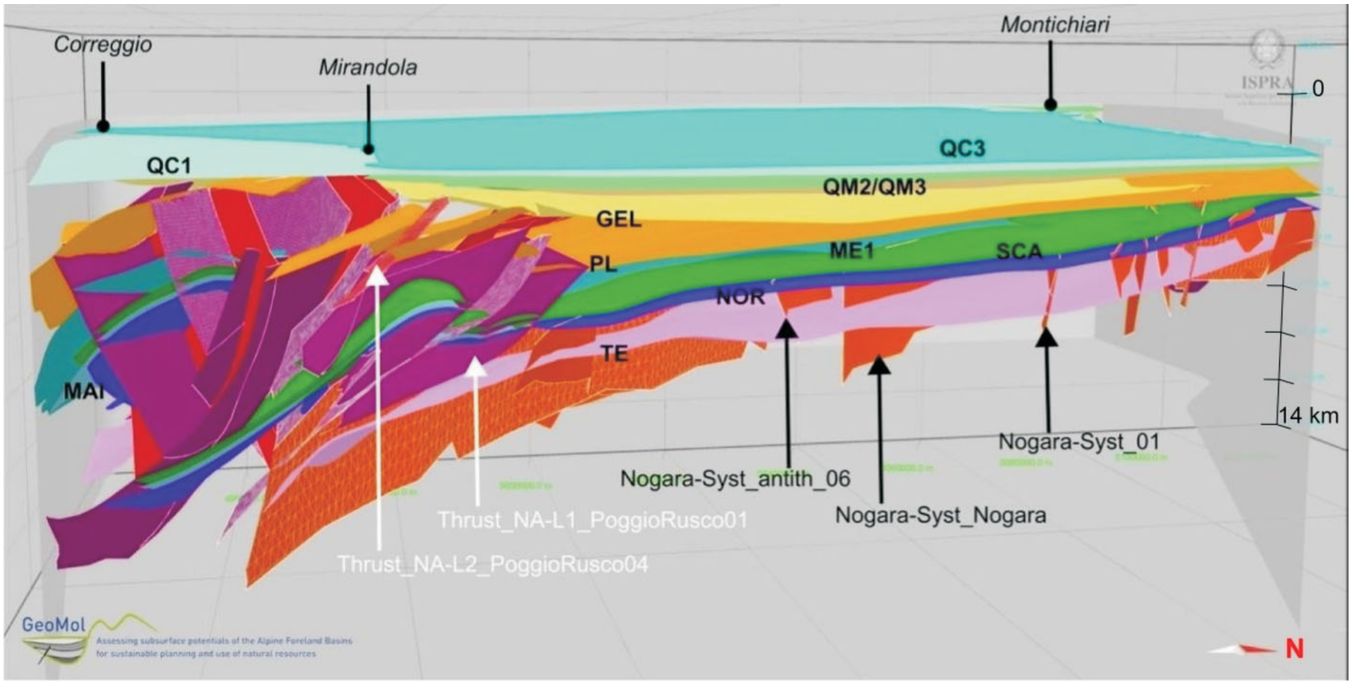

Figure 4. 3D geological model of the central Po Basin (GeoMol Project). The surfaces marked with black labels represent horizons from Trias (TE) up to Pleistocene (from GEL to QC3). The purple surfaces represent the main thrusts, responsible for the Emilia 2012 seismic event. The orange surfaces represent inherited normal faults in the Mesozoic carbonatic succession. The horizontal grid spacing is 10 x 10 km.

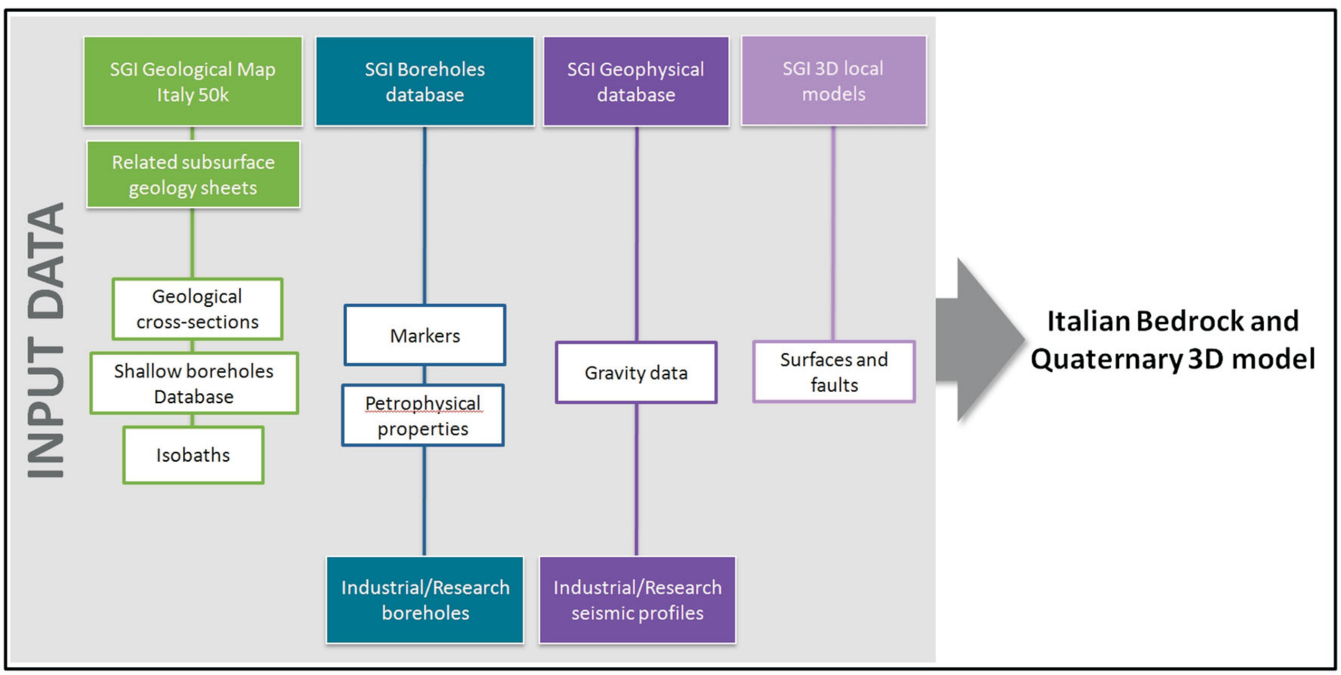

Figure 5. Workflow for the realization of the Italian Bedrock and Quaternary 3D model. All the input data will be harmonized following a structural and stratigraphic scheme based on Geological Map of Italy 1:1,000,000 scale (ISPRA 2011).

3D model applications (e.g. wide basins analysis, geothermal resource assessment, seismotectonics).

Only a small amount of resources derives from institutional funds.

The staff involved in the 3D modelling activities changes based on the budget and timeframe of the projects, the type of applications, the size of the modelled areas. They are field geologists, geomodellers, geophysicists, and GIS experts, generally not full-time involved.

The 3D modelling activities in specific research projects involve also geoscientists from universities or research institutes, and undergraduate or PhD students that use 3D modelling techniques as part of their theses.

Overview of Regional Geological Setting

The geology of Italy is the result of a long series of geological events that include: i) the evolution of the passive margin of the Gondwana continent (Precambrian–Ordovician); ii) the opening and closure of the Rheic ocean (Ordovician–Devonian); iii) the Variscan (or Hercynian) orogeny and the following creation of Pangea (Carboniferous–Triassic); iv) the opening of the Tethys ocean and its closure due to Alpine orogeny, that generated both the Alps (Jurassic–Oligocene) and the Apennines - Maghrebian chains (Upper Oligocene–Present); v) the opening of the Liguro-Provençal and Corsica basins (Lower Miocene); and vi) the opening of the Tyrrhenian basin (Late Miocene).

On this basis, the Italian territory (≈300,000 km^2 on-land) can be subdivided into seven sectors, from north to south: the Alps, the Po Plain, the Apennines, the Apulia foreland, the Calabrian-Peloritan arc, Sicily (that includes the Maghrebian chain and its Hyblean foreland), and Sardinia (Figure 6). Furthermore, the Italian peninsula is characterized by the presence of active volcanoes (i.e., Campi Flegrei, Vesuvio, Etna, Stromboli, and Vulcano) and has frequent earthquakes.

Sardinia island (SA in Figure 6), in the western Tyrrhenian Sea, has preserved the oldest rocks outcropping in Italy, Precambrian-Carboniferous in age, related to the pre-Variscan orogenic history. In the other parts of Italy the Variscan orogeny has been overprinted by the Alpine orogeny.

The Italian portion of the Alps mountain belt extends from the Gulf of Genova in the west to the boundary with Austria and Slovenia, in the east. It can be subdivided into two belts, according to the sense of tectonic transport toward the foreland: a Europe-vergent belt (Al-E in Figure 6) and an Africa/Adria-vergent belt (Al-A in Figure 6), named the Southern Alps (Dal Piaz 2010).

The Europe-vergent belt includes units deriving both from European and African continental crusts and Tethyan ocean domain, displaced towards the Molasse foredeep and European foreland. The Africa/Adria-vergent belt consists of units of non-metamorphic, ophiolite-free, African continental crust, developed inside the Alpine hinterland (retro-wedge). The two belts are juxtaposed along the Periadriatic (or Insubric) lineament (IL in Figure 6).

The Po Plain (PP in Figure 6) developed between the Alps and the Apennines. It represents the common foreland of these oppositely verging fold-and-thrust belts. The outer fronts of the Southern Alps, to the north, and Northern Apennines, to the south, are buried below >7,000 m thick pile of Plio-Quaternary marine-to-continental sediments (Fantoni and Franciosi 2010).

The Apennines geographically extend the length of the Italian peninsula, from north to south (AP/APm in Figure 6); this belt is the result of the convergence between the Alpine orogen and the continental crust of the Africa plate (Adria promontory or Adria microplate). The deformations of the Apennines are superimposed on previous compressional events, responsible for the formation of the Alps during the Late Oligocene-Early Miocene counter-clockwise rotation of the Corsica-Sardinia block. The Apennines include units of African continental crust derived from the Mesozoic Tethys ocean.

In the Apennines since the Miocene the eastward migration of compression has been followed and coupled by the contemporaneous activity and migration of a co-axial extension (in the hinterland), due to the opening of Tyrrhenian basin. The extension has been accompanied and post-dated by magmatic activity.

This tectonic couple (compression - extension) is responsible for the seismic activity that characterizes Italy. Several earthquakes have hit the peninsula in the past ten years, notably connected with either blind or buried thrusts of the Apennines (i.e., 2012 - Emilia Seismic sequence, Mw 5.6 and 5.8) or to the extensional tectonics in the hinterland (i.e., 2009 - L'Aquila, Mw 6.3; 2016/2017 - Central Italy, max Mw 6.5 and four events of Mw >5.0).

Toward the south the Apulia forms the still undeformed foreland of the Apennines belt, as Hyblean foreland is for the Maghrebian (Apennines-Maghrebian) chain in Sicily (respectively AF, HF, and APm in Figure 6). Finally, the Calabro-Peloritan arc (CP in Figure 6), interpreted as a fragment of the Alpine chain migrated toward the SE and overlay the Apennines-Maghrebian belt, where some sectors preserve nearly entire segments of Variscan continental crust, unaffected by Alpine metamorphism.

Data Sources

According to the type of 3D model (shallow or deep, in mountain regions or plain areas), different types of data constitute the main input and constraints. In Italy, geoscience data are generally publicly available through the web Portal of SGI (www.portalesgi.isprambiente.it). They usually have national coverage, although their distribution can vary, with poor density in some areas. Most of the datasets owned and managed by SGI comply with the INSPIRE standard established to ensure that the spatial data infrastructures of the Europe Member States are compatible and usable in a Community and transboundary context (Directive

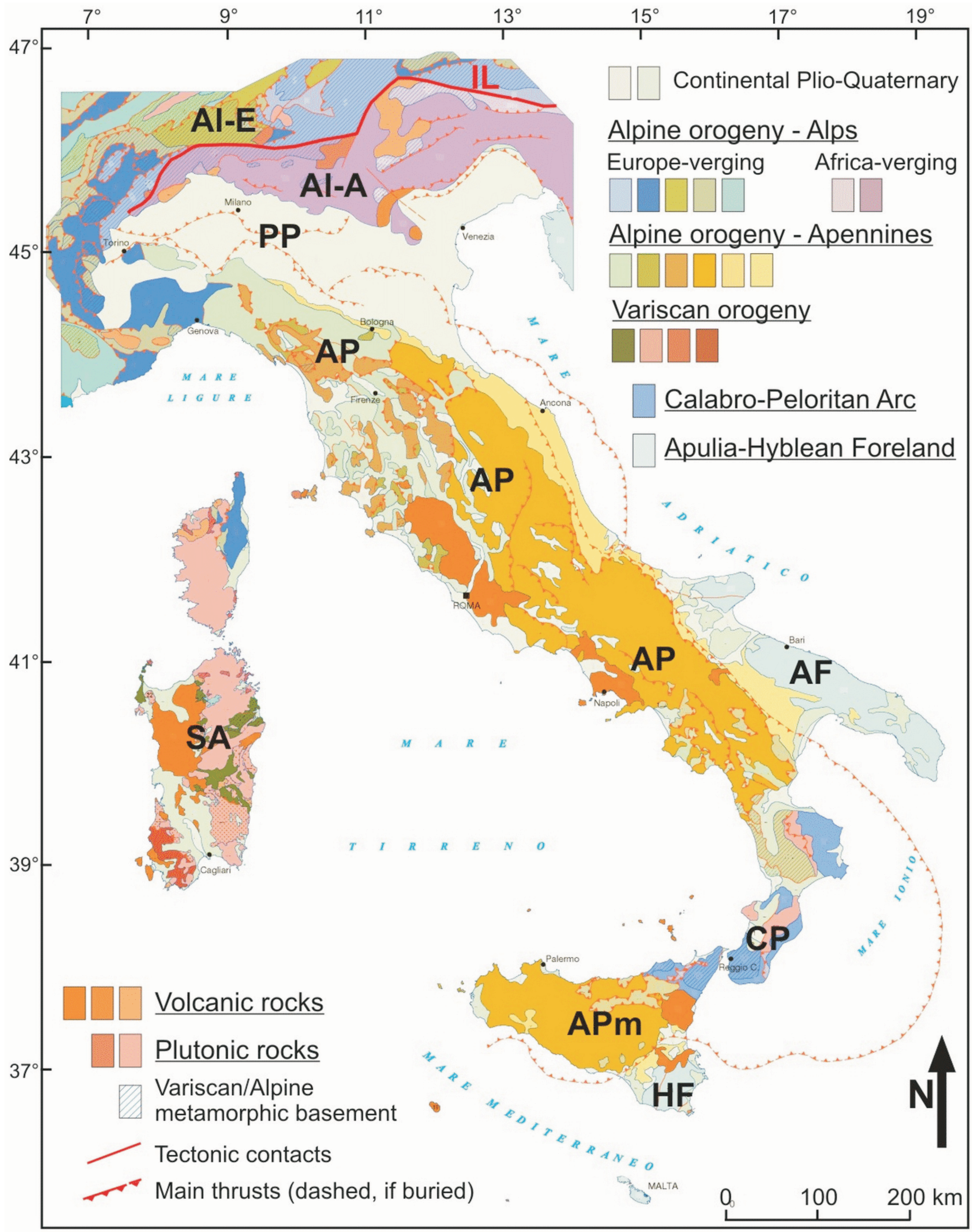

Figure 6. Tectonostratigraphic scheme of Italy (modified after ISPRA 2011). Alps Europe-verging (Al-E), Alps Africa-verging (Al-A), Po Plain (PP), Apennines (AP), Apulia foreland (AF), Calabrian-Peloritan arc (CP), Sicily: Maghrebian chain (APm) and Hyblean foreland (HF), Sardinia (SA), Periadriatic (Insubric) lineament (IL).

2007/2/EC of the European Parliament, https://inspire.ec.europa.eu).

Geological 3D models in deformed areas (e.g. Fossombrone, Vette Feltrine, Polino) are mainly based on surface data deriving from SGI geological map database (CARG DB) where at least unit boundaries, fault traces with measure points, attitudes, shallow boreholes, and cross-sections give constraints on the position of the geological units and geometrical characteristics of structural elements. Seismic reflection profiles and gravity data are used if available in public databases or accessible under confidentiality agreements (e.g., Piadena). Shallow 3D models in plain or urban areas (e.g., Rome, Florence, Fiumicino, Montereale) are built using the SGI boreholes database and geophysical data specifically acquired (e.g., geoelectric field, MASW - multichannel analysis of surface waves, gravity anomalies).

The production of deeper crustal models (e.g., Po Basin, RETRACE-3D, Conero, Pliocene clays), both in mountain and plain regions or in offshore areas, is based on data, such as seismic reflection profiles, deep wells for hydrocarbon and geothermal exploration, geophysical data, seismicity distribution, coming from national public database or private repositories (on request). Additional inputs are derived from published maps on Moho discontinuity, lithosphere thickness, heat flow, and seismic tomography.

Most of the data needed as input for 3D model production are made publicly available by the SGI through its web Portal (Figure 3):

- geological map database (CARG DB);
- database of subsoil investigations according to the Law 464/84. This national Law establishes the obligation to notify to the SGI all the information on excavations, perforations and geophysical surveys driven to depths greater than 30 meters from ground level and, in the case of tunnels, more than 200 meters in length. Data correspond to the information declared in the communication without any interpretation during digitalization;
- database of composite log of deep boreholes for hydrocarbon and geothermal exploration and production. According to the national law, the database collect information on boreholes publicly available, one year after the end of the mining license they were drilled;
- gravity anomaly data measured at more than 358,000 stations on the Italian territory.

Additional data may be collected by other public institutes such as Istituto Nazionale di Geofisica e Vulcanologia (INGV), Consiglio Nazionale delle Ricerche (CNR) and Ministero Sviluppo Economico (MISE):

- Italian Seismological Instrumental and Parametric Data-Base (ISIDe) - INGV (ISIDe working group 2016) that contains the parameters of hundreds thousands earthquakes occurred in the Italian region in the time frame between 01-01-1985 and today. The locations are based on more than 500 stations of the National Seismic Network operated by Istituto Nazionale di Geofisica e Vulcanologia (INGV), and regional and international networks operated by several providers;
- Database of seismogenic sources, DISS 3.2.1 - INGV (DISS Working Group 2018), that is a compilation of potential sources for earthquakes larger than M 5.5 in Italy and surrounding areas;
- seismic lines and exploration reports - MISE (ViDEPI Project). The ViDEPI Project enables the free access to information on oil and gas exploration activities, according to national rules on industrial data confidentiality;
- seismic lines for deep crust exploration - CNR (CROP Project). The CROP Project was a multidisciplinary research program, involving multiple Italian agencies, focusing on the Italian lithosphere. During the '90s, the project collected, processed, and interpreted deep reflection seismic profiles on land (approx. 1,250 km) and at the sea (approx. 8,700 km).

Other relevant raw data, particularly those collected by oil and gas private companies, can be used on request under rules defined by confidentiality agreements. In general, no restriction applies to derivative models produced from these data, but the original data cannot be redistributed. Despite the overall high quality, distribution, and resolution of geoscience data in Italy, the resolution of the 3D models need to be defined on a case-by-case basis, considering the availability of the most relevant data for the target applications and uses of each 3D model.

3D Modelling Approach

The geological characteristics of the Italian peninsula, the type of available geoscience data, and the uses and applications of the 3D models, led the SGI to design a workflow for 3D explicit modelling that provides a significant control to the geologists in charge for the 3D model building. The workflow (Figure 7) proposed by D'Ambrogi et al. (2004) and then implemented by D'Ambrogi et al. (2010), Maesano et al. (2014), allows the user to manage and integrate input data and constraints characterized by different domains of the vertical axis: time (e.g., seismic lines, velocity data, time-depth or time velocity curves of wells) and depth (e.g., field data, published geological maps, cross sections, isobath and isopach maps). Separate steps in the workflow characterize each domain, sometimes connected to check the validity and consistency of the analysis and outcome. After the time-depth conversion of the 3D model (if needed) the steps are completely developed in the depth domain. The main phases of the workflow (Figure 7) are:

1) Data: harmonization and interpretation;
2) Elaboration of the 3D model in the time domain;
3) Calculation of the 3D velocity model;
4) 3D model time-depth conversion;
5) Consistency check and refinement of the 3D model in the depth domain;
6) Construction of the final 3D model.

The principal software used for 3D model production at SGI is MOVE (MVE Ltd.), that enables an easy integration of a wide range of data including outcrops, boreholes, and seismic lines, with an active role of the expert knowledge of the geomodellers, and supports the major needs for structural analysis of active and seismogenic faults in Italy. In order to better manage seismic data and time-depth conversion in areas with high geological complexity, a dedicated tool has been developed for 3D velocity model creation and time-depth conversion (Vel-IO 3D, Maesano and D'Ambrogi 2017), and is fully integrated into the modelling workflow. Vel-IO 3D is composed of three scripts, written in Python 2.7.11, that perform different tasks: i) 3D instantaneous velocity model building, ii) velocity model optimization, iii) time to depth conversion (Figure 8A). Further, to improve additional analyses based on 3D geological models, SGI designed and tested methods for: i) analysis of sedimentary basins (Figure 8B) (Maesano and D'Ambrogi 2016), and ii) fault restoration and sediment decompaction for long-term slip rates calculation and active faults characterization (Figure 8C) (Maesano et al. 2015).

Clients

The 3D models produced by SGI are mainly used by public authorities; these include, at the national level, i) the Civil Protection Department, ii) Ministries (i.e. Environment, Economic Development), iii) Research Institutes and Universities, iv) Regional authorities, and at international level, the European Union. In some case, the clients (e.g. National Civil Protection Department, European Union) commissioned and funded directly the realization of the 3D geological model for specific purposes such as seismotectonic characterization, monitoring of soil and subsoil conditions during infrastructure planning, geothermal assessment. On the other hand, the research institutes, universities, and other users are interested in more general subsurface geological information derived from 3D geological models, especially for scientific or communication purposes.

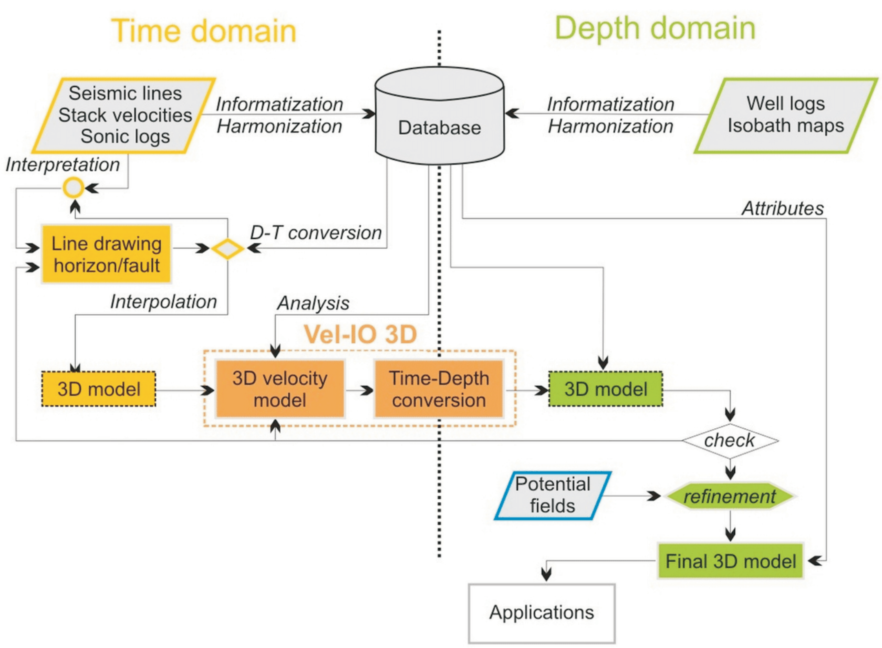

Figure 7. 3D modelling workflow implemented at SGI (modified after Maesano and D'Ambrogi 2017).

Recent Jurisdictional-Scale Case Study Showcasing Application of 3D Models

Geological 3D models at a regional scale, investigating depth of several kilometers, have been realized in Italy, including offshore areas (8 and 11 in Figure 3), and others are under construction. The 3D geological model of the Central Po Basin is definitely the most comprehensive for the number of modelled stratigraphic units (15 horizons from Triassic up to Holocene) and faults (170 surfaces, including thrusts and normal faults), and for the geological complexity (Figure 4). This model, produced during the GeoMol Project will constitute the starting point for the extension of the modelling to the entire Po Basin (an area of more than 30,000 km^2 extended on four different administrative regions) in the upcoming HotLime - GeoERA Project (12 in Figure 3). At the end, more than 25,000 km of seismic reflection profiles and 400 wells will constitute the input dataset for this enlarged area.

The workflow is that established and implemented by SGI (Figure 7), with the integration of geological with geophysical data, through the comparison of a preliminary 3D model with gravity anomalies map, the geometric refinement, and the check of model consistency.

The already completed part of this upcoming enlarged model (the Central Po Basin – GeoMol Project) represented the basic geological input for the assessment of geothermal re-

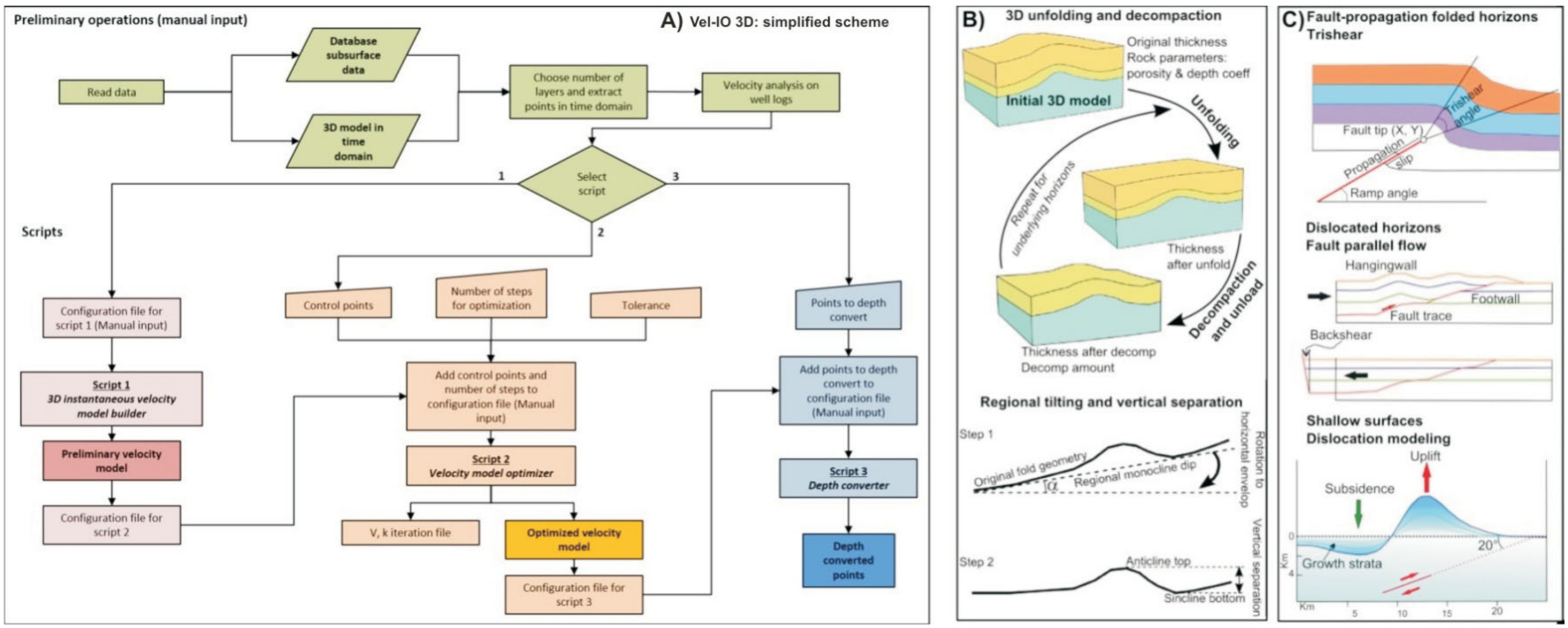

Figure 8. A) Simplified flowchart for Vel-IO 3D tool; **B)** restoration workflow for basin analysis; **C)** characterization of folds and faults.

source, but also contributed like never before to identify, and fully parameterize new seismogenic sources and active faults.

Current Challenges

SGI increasingly embraced 3D geological modelling to support its institutional mandate of production and dissemination of geoscience data and information. Despite the major improvements modelling workflow and methods for the analyses have undergone, several aspects are still underdeveloped.

Current challenges involve not only some methodological topics, such as the calculation and visualization of uncertainties associated with the 3D models, and the parameterization of 3D volumes, but also technical aspects such as the creation of an IT structure enabling the storage and managing of 3D geological models. Moreover, SGI participated in the EU Project EPOS - European Plate Observing System for the development of the Thematic Core Service (TCS) "Geological Information and Modeling"; as regards the 3D geological models, the TCS focuses on promotion and implementation of standards for metadata and accessibility.

Some test of uncertainties representation has been included already in static 3D model-derived maps (Figure 9) produced for the Central Po Basin 3D model (ISPRA 2015). In this case, data density has been considered as the expression of the uncertainty; where data density is low, the uncertainty is high (and vice versa), with uncertainty generally increasing for deeper horizons (with data density decreasing with depth). However further steps are needed to improve the communication of the quality of 3D models and uncertainty of the rock parameters, especially when 3D models are applied to societal issues.

Lessons Learned

The SGI has been active in 3D geological modelling for 20 years now; the lessons learned over this time span can be summarized as follows:

- 3D geological modelling is currently the most important tool for a comprehensive understanding and representation of geological structures;
- the implementation of a dedicated workflow for 3D geological modelling should take into account the specific geological characteristics of the national territory, the type of available data, the most common applications of the 3D geological models;
- a large amount of informatized geoscience data is not sufficient to support 3D modelling activity if data are not structured taking into account the 3rd dimension. GSOs at the national level should harmonize the geometrical content of their database;
- 3D geological models are easy to read and use only for geologists; in order to exploit their informative power, especially towards non-geologist stakeholders, a greater effort is needed in the definition of user friendly formats, accompanied by a clear description of their reliability.

Next Steps

SGI will implement its 3D modelling activity through the following steps:

1) enlargement of the number of the SGI geologists involved in the modelling activities in order to be able to answer to the increasing

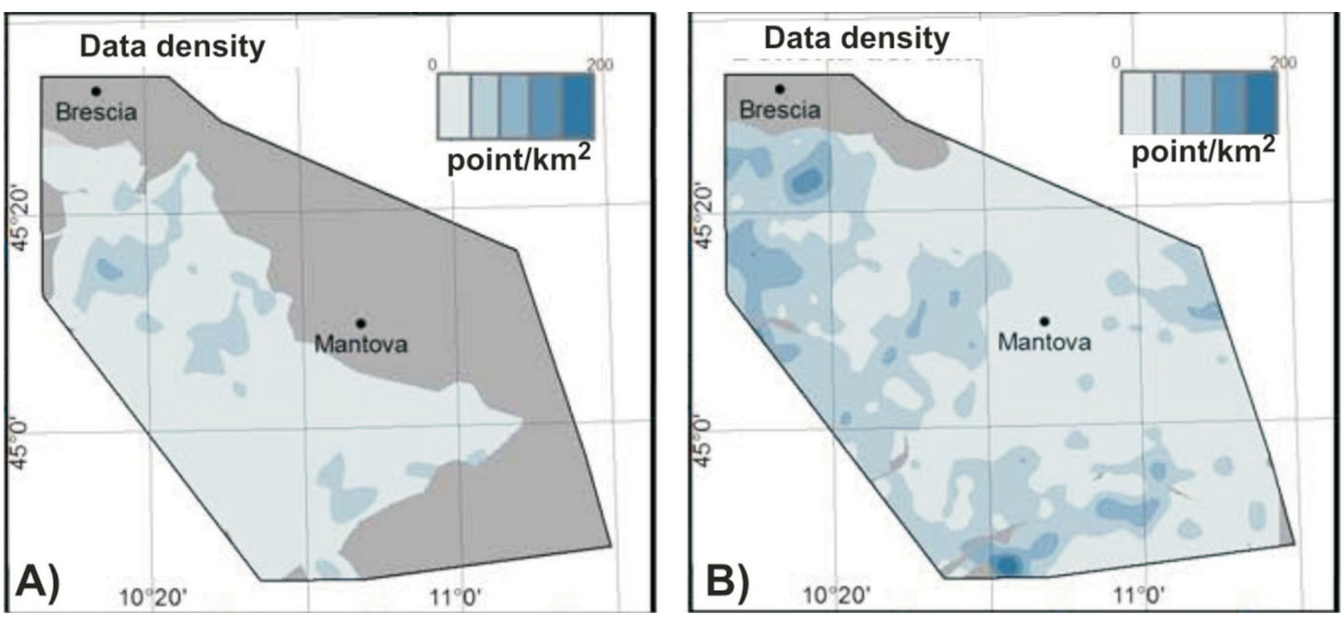

Figure 9. Uncertainty representation through data density map. Examples from the GeoMol Project: map **A)** deeper horizon, map **B)** shallower horizon.

need for knowledge of subsurface geology;
2) definition of national standard workflows for 3D modelling and analysis, in collaboration with regional geological surveys, and with the contribution of research institutes and universities;
3) building of an Italian Bedrock and Quaternary 3D model;
4) design and implementation of a national 3D models database strictly linked to the more traditional national geological database;
5) development of visualization and dissemination tools to engage a wider audience of 3D geological model users.

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