Mean density map for the Italian region by GIS techniques

V. BAIOCCHI[(1)], M. CRESPI[(1)] and F. RIGUZZI[(2)]

[(1)] *DITS - Area di Topografia, Università La Sapienza, Roma, Italy*
[(2)] *Istituto Nazionale di Geofisica, Roma, Italy*

Abstract. The knowledge of the mean density of the masses between the Earth's surface and the geoid ("topographic masses") is remarkably interesting for several geodetic and geophysical investigations; for this purpose, it is very useful to manage these data in digital form. At present the only information available about the mean density of the Italian region is the 1:1 000 000 scale graphical map, published by Vecchia in 1955. This map was drawn by computing the mean densities based on many geological maps and profiles, and grouping these values into 8 classes ranging from 1.8 and 3.4 g/cm^3, each class being 0.2 g/cm^3 wide. By first scanning the graphical map, the raster file was then georeferenced in the WGS84 reference frame, taking special care to modelling and removing the deformations due both to the paper and the scanning process. Finally, ASCII files of the mean density values sampled on a 15" $\times$ 20" (latitude $\times$ longitude) regular grid and a vector file for convenient data manipulation and representation were produced. The main steps of the data processing were performed in the Intergraph MGE environment and a Fortran 77 service program was written in order to produce the ASCII files in a suitable form.

1. Introduction

Italy is an extremely variable region both from a geological and a geomorphologic point of view. This fact implies great variability of the local gravity field with high gravity anomaly (Bouguer and isostatic) values and variations over limited areas.

The precision of the gravity reductions needed to compute these gravity anomalies and also of the geoidal undulation estimates is limited by the poor knowledge of the topographic mass densities. This effect is obviously strictly related to the height. In particular, it is possible to show

Corresponding author: F. Riguzzi, Istituto Nazionale di Geofisica, Via di Vigna Murata 505, 00143 Roma, Italia; phone: +39 06 518602266; fax: +39 06 5041303; e-mail: riguzzi@ing750.ingrm.it

that a density error of 10% may cause differences of about 1 mgal every 100 m of height in the gravity reduction computations (even excluding the classical topographic corrections).

In 1955 Vecchia elaborated a colour paper map of the mean density of the topographic masses above the sea level of the Italian region, aiming to lower these errors and to provide a useful tool for improving the quality of the gravimetric measurement reductions. This map was used to compute the isostatic reduction tables of the gravity measurements (Ballarin, 1960) and to draw the gravimetric map of Italy (Ballarin et al., 1972).

In this context it is useful to briefly recall the principal applications of the mean density of the topographic masses both in geodesy and in geophysics (Heiskanen and Moritz, 1967; Torge, 1989):

1. estimation of local quasigeoid by remove-restore technique (Barzaghi et al., 1997):

- computation of the contributions to free-air anomalies due to topographic masses (terrain correction) in the remove step;

- computation of the free-air anomaly gradient.

2. computation of local geoid from local quasigeoid:

- computation of the mean gravity along the plumb line by the Prey reduction, then:

$$N = \zeta + \frac{\overline{g} - \overline{\gamma}}{\overline{\gamma}} H. \tag{1}$$

- computation of the Bouguer anomaly Δg_B, then:

$$N \cong \zeta + \frac{\Delta g_B}{\overline{\gamma}} H. \tag{2}$$

(N: geoidal undulation, ζ: undulation of the quasigeoid, $\overline{g}$: mean gravity along the plumb line, $\overline{\gamma}$: suitable value of normal gravity, H: orthometric height).

3. investigation of the structure of the earth's crust and upper mantle:

- computation of the Bouguer Δg_B and isostatic Δg_I anomalies.

4. gravity inverse problem, applied gravimetry:

- removal of the influence of known masses;

- constraints on density contrast in the iterative solution according to the optimization method.

5. computation of curvature of plumb line and orthometric correction:

- computation of the mean gravity along the plumb line $\overline{g}$ by the Prey reduction.

Note that it is possible to roughly evaluate the error in the geoidal undulation N due to the error in the mean density starting from Eq. (2); in fact if we put H=1000 m and assume a 10% error in the mean density, we have an error of 10 mgal in the Bouguer anomaly and an error of 1 cm in the geoidal undulation. Moreover, it has to be underlined that the assumed 10% error in the mean density is not extreme if compared with the large variability of the density in Italy with respect the standard density value 2.67 g/cm^3.

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2. The paper map

The mean density map was drawn at a 1:1 000 000 scale according to the conical Lambert projection referred to the Italian datum (ROMA40 ellipsoid).

The massive effort made by Vecchia was devoted to inspecting all the existing geologic maps (about 300), profiles, papers, field reports and rock density tables. From these tables he established a density scale from 1.8 to 3.4 g/cm^3 divided into 8 classes, each class 0.2 g/cm^3 wide; this interval being in agreement with the mean precision achievable by the analysis of the profiles. Moreover, an additional class for water (density 1.0 g/cm^3) was considered.

Densities were estimated as weighted means of the densities relative to each formation thickness and belonging to the same geologic series along the vertical, from the surface to the sea level. The 9 mean density classes were represented in the map by 9 different colours contoured by 0.2 mm black lines; the geographic grid was drawn with similar lines.

3. The procedure

The density values of the paper map simply become usable if they are converted into digital files. The procedure adopted is based on the use of GIS techniques (Burrough and McDonnel, 1998).

First, we carried out a black/white scanning of the map, instead of a color one. This would strongly limit the memory requirement and avoid constant density areas (homogeneous areas) being represented by more than one colour, due to lack of uniformity in the colour of the paper map. As the map is larger than A0 two raster files were created.

These files were georeferenced and unified by the *Iras B* module of MGE with a mean error (30 m) lower than the standard graphic error for the paper map considered (200 m), following some well-tested procedures. More specifically, a contemporary georeferencing and coordinate transformation according to a latitude and longitude regular grid was performed by a five degree affine transformation:

$$x' = a_0 + a_1y + a_2x + a_3x^2 + a_4xy + a_5y^2 + \ldots.$$

$$y' = b_0 + b_1y + b_2x + b_3x^2 + b_4xy + b_5y^2 + \ldots.$$

as a rectangular grid is more convenient than a conical one to perform the subsequent operations. The transformation parameters were estimated using the known coordinates of all the intersection points between meridians and parallels.

The following step was to bound the homogeneous areas by long and generally continuous stripes of black pixels. It was then easy to assign them a colour similar to the original by using an image processing commercial software (Paintshop); we chose a 16 colour palette to limit the memory storage.

The georeferenced raster colour file was processed by the *Iras C* module of MGE to
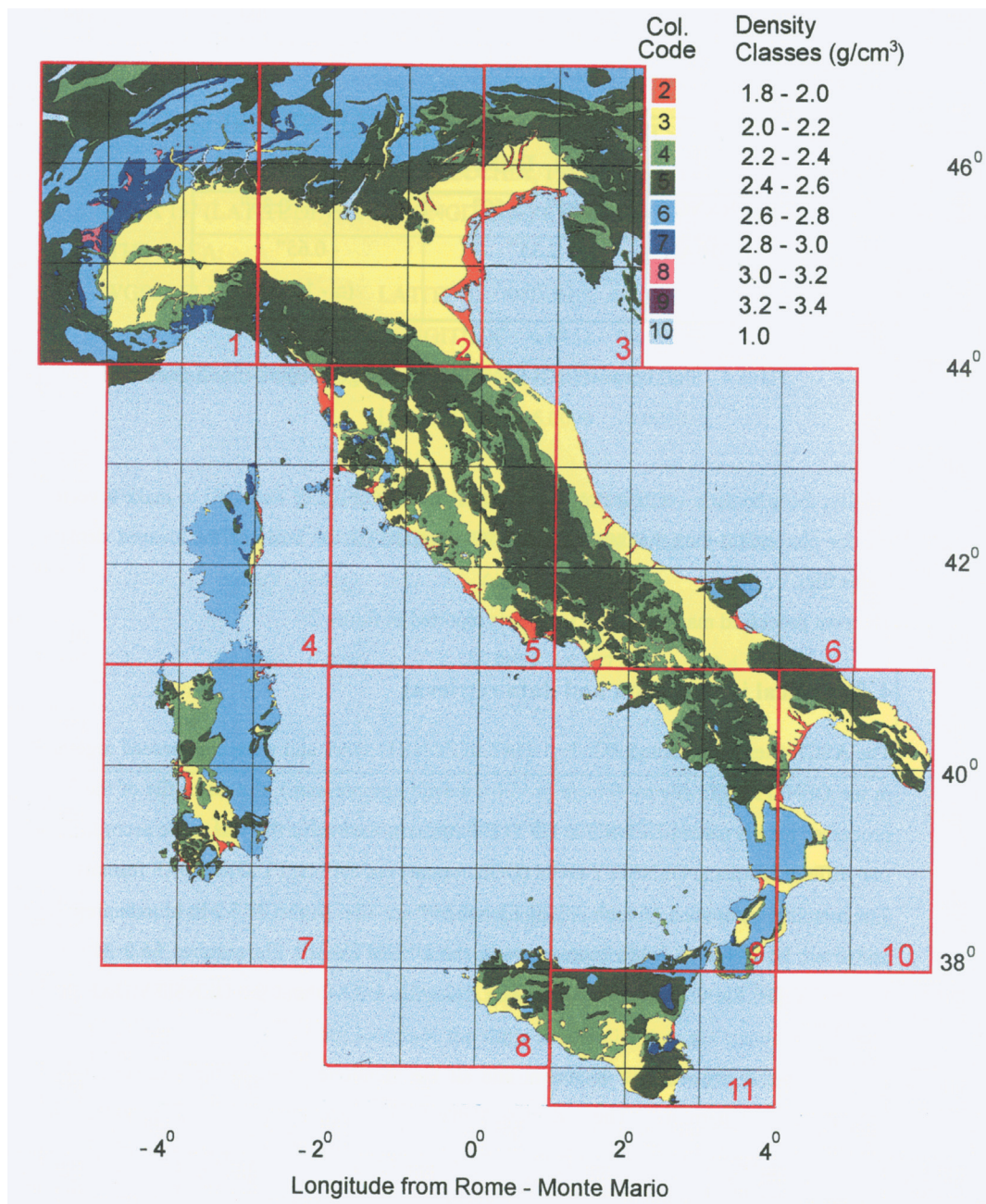
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Fig. 1- The post processed map with the 11 zones.

automatically obtain an ASCII file with the density codes (one code for each density class).

   This last step implied a discretization of the raster file according to the required resolution (15" × 20"), so that a density code could be assigned to each finite element (pixel) stemming from the discretization. Note that the resolution adopted (corresponding approximately to a 450 m × 450 m area) was chosen taking into account the standard graphic error, the requirements of

the geodetic and geophysical investigations and the memory requirements.

The number of pixels exceeded 4 million, so that it became necessary to split the map into 11 zones to overcome storage problems during the processing; accordingly 11 files containing density codes were produced automatically.

A suitable Fortran 77 program was implemented to clean these files from spurious code values (0 and 1) and to convert them into 11 ASCII files with density a value (density class) and a position for each pixel. In particular, both the ROMA40 and the WGS84 geographic coordinates were indicated, the latter was derived by adopting a mean shift with respect to the former according to the values estimated in the frame of IGM95 GPS campaign adjustment (Surace, 1997). Note that both for latitude and for longitude the shifts are smaller than the standard graphical error, provided the global longitude shift from Greenwich to Roma-Monte Mario (12° 27' 08.40") is removed.

The map, after processing, with the 11 zones is reproduced in Fig. 1.

4. Technical information and data retrieval

The ASCII files were named ZONE_1.DAT to ZONE11.DAT and were compressed together in the DENSITY.ZIP file by Winzip (v. 5.6 - default compression); the file of the post-processed map is DENSITY.TIF (TIFF format).

The memory occupation of each ASCII file ranges from 12.6 Mb to 37.3 Mb (uncompressed) and from 1.5 Mb to 4.5 Mb (compressed); the DENSITY.ZIP file requires 36.0 Mb and the DENSITY.TIF file 0.25 Mb.

It is possible to request this document and all the files mentioned at the internet address riguzzi@ing750.ingrm.it. The density map is available at the Internet site Web site http://ing712.ingrm.it/data_www/Geodesy/geodesy.html of the Istituto Nazionale di Geofisica.

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