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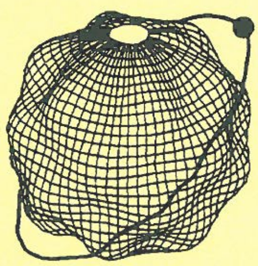

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MEAN DENSITY MAP FOR THE ITALIAN REGION BY GIS TECHNIQUES

Valerio Baiocchi (1), **Mattia Crespi** (1) and **Federica Riguzzi** (2)

(1) DITS – Area di Topografia, Universita` *La Sapienza* di Roma, Roma, Italy

(2) Istituto Nazionale di Geofisica, Roma, Italy

Abstract

The knowledge of the mean density of the masses between the earth surface and the geoid is remarkably interesting for several geodetic and geophysical investigations; in this respect, it is very useful to manage these data in digital form.*

At present the unique 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 computing the mean densities on the basis of many geological maps and profiles, by grouping these values in 8 classes ranging between 1.8 and 3.4 g/cm^3, each class 0.2 g/cm^3 wide. An additional class includes the water density (1.0 g/cm^3).

Starting from the graphical map scanning, the raster file was georeferenced in the WGS84 reference frame, devoting a special care to model 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" (latitude) ×20" (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 Fortran77 service program was written in order to produce the ASCII files in a suitable form.

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1. Introduction

Italy is an extremely variable region from a geological and geomorphologic point of view. This fact implies a 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 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 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 realized a paper coloured map of the mean density of the topographic masses above the sea level of the Italian region, with the aim to lower these errors and to provide a useful tool to improve 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, Palla and Trombetti, 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 a local quasigeoid by remove-restore technique (Barzaghi et al., 1997)

   a - computation of the contributes to free-air anomalies due to the residual topographic masses (terrain correction) in the remove step

   b - computation of the free-air anomaly gradient

   c - computation of the residual contribution to the anomalous potential in the restore step

2) Computation of a local geoid from a local quasigeoid

   a - computation of the mean gravity along the plumb line $\overline{g}$ by the Prey reduction, then:

$$N = \zeta + \frac{\overline{g} - \overline{\gamma}}{\overline{\gamma}} H \quad (1)$$

   b - computation of the Bouguer anomaly Δg_B, then:

$$N \cong \zeta + \frac{\Delta g_B}{\bar{\gamma}} H \qquad (2)$$

(N: geoidal undulation, ζ: height anomaly, $\bar{g}$: mean gravity along the plumb line, $\bar{\gamma}$: suitable value of normal gravity)

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

a - removal of the influence of known masses

b - 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 $\bar{g}$ 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 (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.

2. The paper map

The mean density map was drawn at 1:1.000.000 scale according to the conical Lambert projection referred to the Italian datum (ROMA40 ellipsoid).

A large effort was done by Vecchia to inspect 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 in 8 classes, each class 0.2 g/cm^3 wide, being this interval in agreement with the mean precision achievable by the analysis of the profiles. Moreover, an additional class for the water (density 1.0 g/cm^3) was considered.

Densities were estimated as weighted means of the densities relative to each formation thickness 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; with similar lines was drawn the geographic grid.

3. The procedure

The density values of the paper map obviously become simply usable if they are converted into digital files. The procedure adopted to obtain these files is based on the use of GIS techniques (Burrough and McDonnel, 1998), according to the scheme of figure 1.

First, we carried out a black/white instead of a colour scanning of the map, in order to strongly limit the memory requirement and to avoid that constant density areas (homogeneous areas) were represented by more than one colour, due to lack of uniformity in the colour of the paper map. Two raster files were created, since the map has dimensions greater than A0. Great care was devoted to control the resolution obtained passing from colours to black and white and to calibrate the threshold value in order to memorize as black only the pixels of meridians, parallels and boundary lines between different density fields. The two files were saved in the binary raster format *cit*, which is the Intergraph georeferenciable format.

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 considered paper map (200 m), following some well tested procedures. Particularly, a contemporary georeferencing and coordinate transformation according to a latitude and longitude regular grid was performed by a five degree affine transformation as a rectangular grid is more convenient than a conical one to perform the subsequent operations:

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

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

Where $a_0 \ldots a_{20}$, $b_0 \ldots b_{20}$ are the parameters; x', y' are the coordinates in the output georeferenced raster file and x, y are the coordinates in the input raster files.

The transformation parameters were estimated using the known coordinates of all the intersection points between meridians and parallels (Table 1).

EQUATIONS	216
PARAMETERS	84
RMS OF TRANSFORMED COORDINATES (m)	30

Table 1 - Affine transformation parameters estimation features

After this step, the homogeneous areas were bounded by long and generally continuous stripes of black pixels. Therefore, it was easy to assign them a colour similar to the original by 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* in order to obtain automatically 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 adopted resolution (approximately corresponding 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 pixel exceeded 4 millions, so that it was necessary to split the map into 11 zones in order to overcome storage problems during the processing (Table 2); correspondingly, 11 files containing density codes were produced automatically.

A suitable Fortran77 program was implemented to clean these files from spurious code values (0 and 1) and to convert them into 11 ASCII files with density value (density class) and position of each pixel (Table 3).

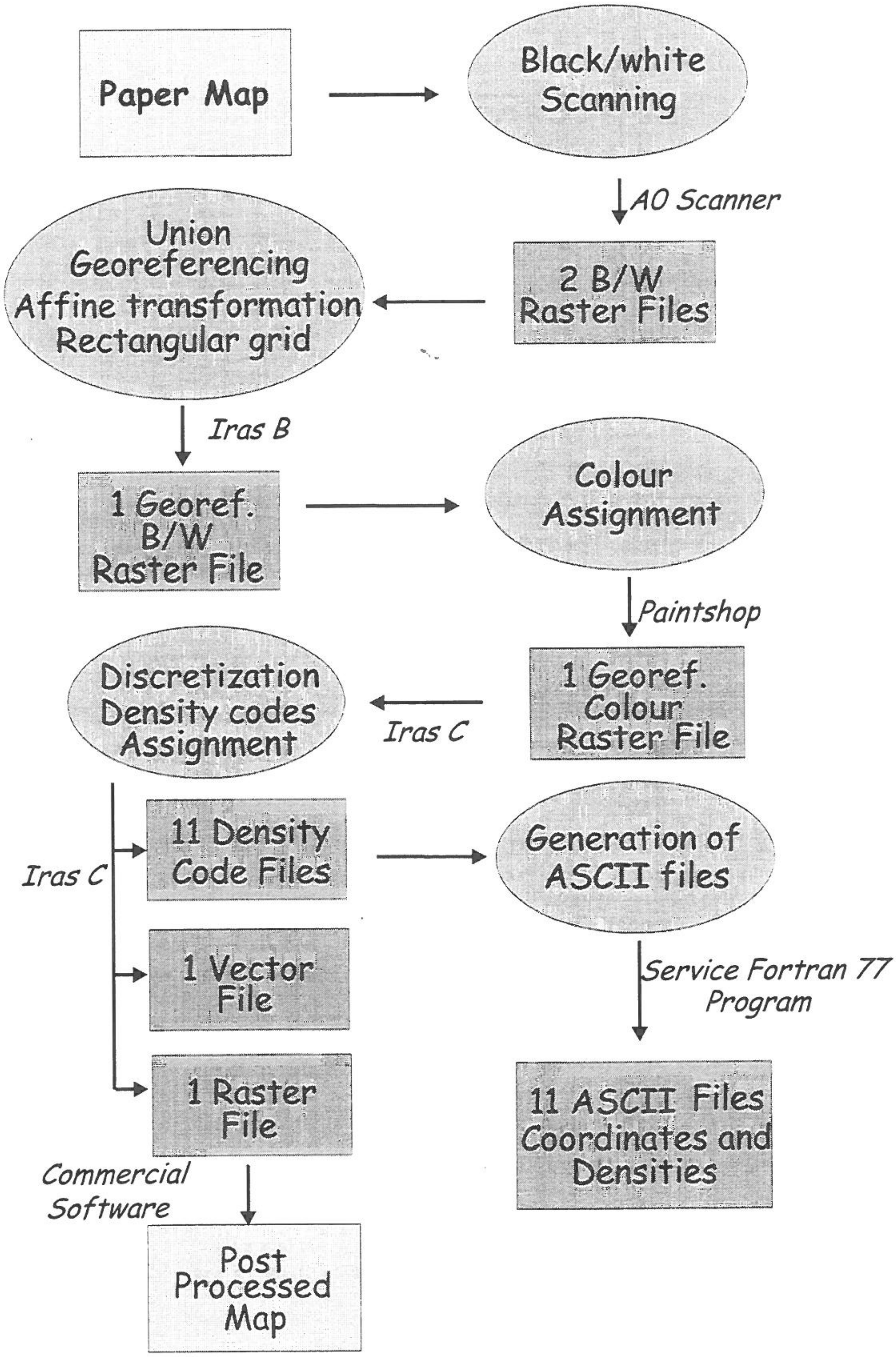

Fig.1: Scheme of the procedure used to achieve data files from the paper map.

ZONE	LOCATION (ROMA40 DATUM) LATITUDE LONGITUDE	PIXEL NUMBER
1	44°00'00" ÷ 47°00'00" - 6°00'00" ÷ - 3°00'00"	378000
2	44°00'00" ÷ 47°00'00" - 3°00'00" ÷ 0°00'00"	388800
3	44°00'00" ÷ 47°00'00" 0°00'00" ÷ 3°00'00"	288800
4	41°00'00" ÷ 44°00'00" - 5°00'00" ÷ - 2°00'00"	388800
5	41°00'00" ÷ 44°00'00" - 2°00'00" ÷ 1°00'00"	388800
6	41°00'00" ÷ 44°00'00" 1°00'00" ÷ 5°00'00"	518400
7	38°00'00" ÷ 41°00'00" - 5°00'00" ÷ - 2°00'00"	388800
8	37°00'00" ÷ 41°00'00" - 2°00'00" ÷ 1°00'00"	518400
9	38°00'00" ÷ 41°00'00" 1°00'00" ÷ 4°00'00"	388800
10	38°00'00" ÷ 41°00'00" 4°00'00" ÷ 6°04'06"	266400
11	36°38'45"÷ 41°00'00" 1°00'00" ÷ 4°00'00"	175500

Table 2 - Zones and corresponding locations

MEAN DENSITY OF THE MASSES FROM THE EARTH SURFACE
TO THE SEA LEVEL IN ITALY (VECCHIA, 1955)
ON A 15" (LATITUDE) x 20" (LONGITUDE) REGULAR GRID WITHIN
THE AREA:

WGS84 ELLIPSOID :	LATITUDE	47.0007 - 44.0007	
	LONGITUDE	6.0452 - 9.0452	
ROMA40 ELLIPSOID:	LATITUDE	47.0000 - 44.0000	
	LONGITUDE	-6.0000 - -3.0000	

P.N.	WGS84 ELLIPSOID		ROMA40 ELLIPSOID		DENSITY	
	LATITUDE (deg)	LONGITUDE (deg)	LATITUDE (deg)	LONGITUDE (deg)	INTERVAL (g/cm3)	
1	46.9986	6.0480	46.9979	-5.9972	2.4	2.6
...	....	....	....	....	....	....
...	....	....	....	....	....	....

Table 3 – Header and beginning of the output ASCII file

In particular, both the ROMA40 and the WGS84 geographic coordinates were indicated, the latter 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) (Table 4).
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.

	LATITUDE SHIFT WGS84 - ROMA40	LONGITUDE SHIFT WGS84 - ROMA40
RANGE	2.20" ÷ 2.50"	- 1.65" ÷ 0.35"
MEAN	2.35" (≅ 70 m)	- 0.65" (≅ - 15 m)

Table 4 - Shift between ROMA40 and WGS84 geographic coordinates

Finally, the automatic vectorizator of the *Iras C* module of *MGE* was used to make a vector file for convenient data manipulation and visualization on the basis of the cleaned density codes files.

The post processed map with the 11 zones is reported in figure 2.

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 raster file of the post processed map is named DENSITY.TIF (TIFF format); the vector file was made according to two different formats: DENSITY.DGN (DGN format) and DENSITY.DXF (DXF format).

The memory occupation of each ASCII file range 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, the DENSITY.TIF file 0.25 Mb, the DENSITY.DGN file 1.3 Mb and the DENSITY.DXF 20.0 Mb.

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

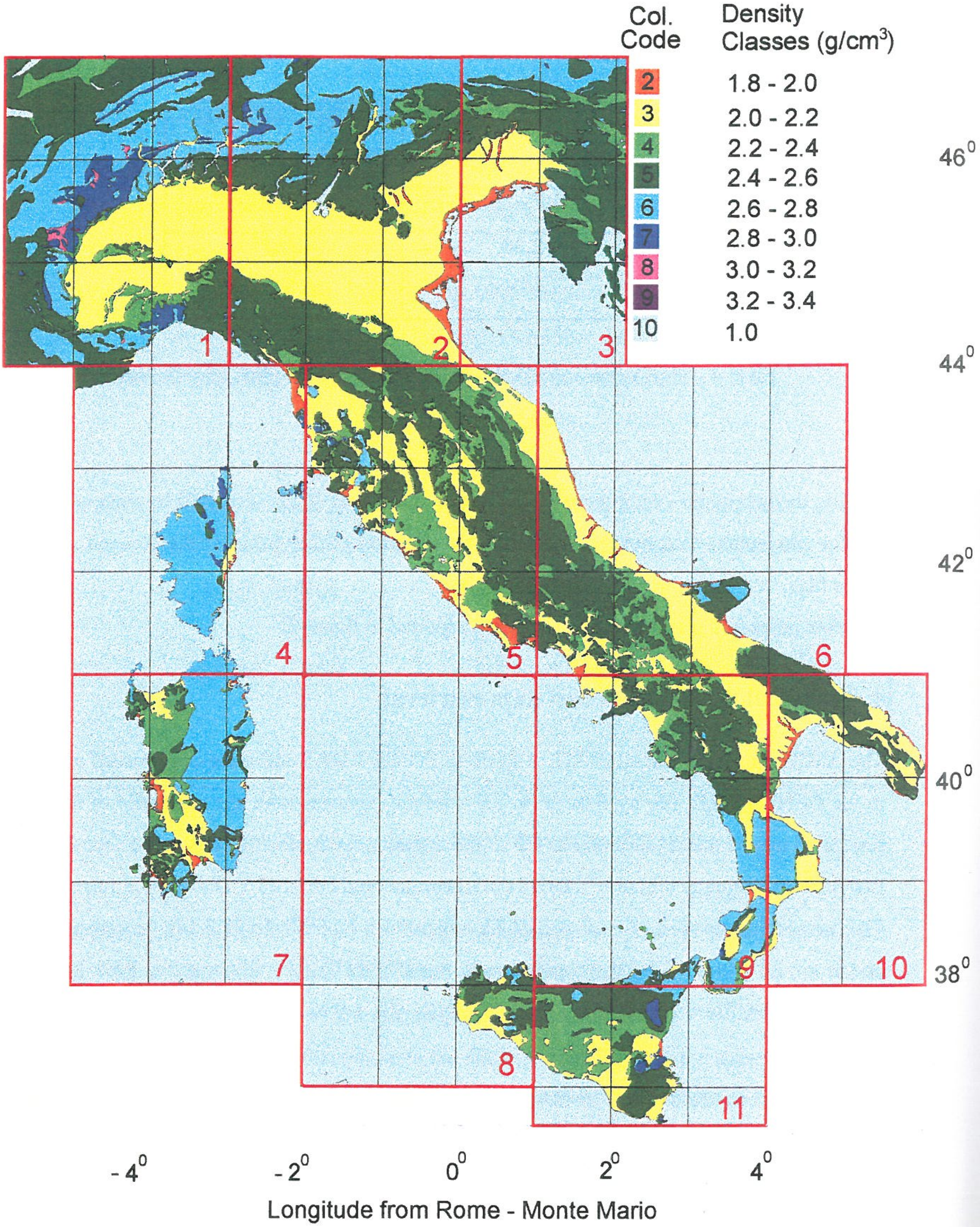

Fig.2: The post processed mean density map; red squares represent the 11 zones constituting each one an ASCII file of coordinates and density values.

Acknowledgments

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