A GEOCHEMICAL-GEOLOGICAL-GEOPHYSICAL APPROACH TO ESTIMATE U AND Th ABUNDANCES IN CENTRAL APENNINES CRUST, FOR TESTING GEONEUTRINOS AS A TOOL OF DEEP EARTH'S INTERIOR INVESTIGATION

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Amongst the various and exotic particles which populate the sub-atomic world, geoneutrinos, anti-neutrinos produced by radioactive beta decay of unstable elements contained in terrestrial rocks, are of particular relevance for Earth Sciences. The main radio-nuclides are ^{40}K, ^{232}Th and ^{238}U. They are also responsible for a large part of the terrestrial heat generation, thus a better understanding of the distribution of this radio-nuclides is essential for the Earth's thermal models and represent a valid constrain of the BSE model (Bulk Silicate Earth; McDonough *et al.*, 1992; Palme & O'Neill, 2003). These reasons explain the increasing interest in geoneutrinos coming from Earth Sciences, in concomitance with the improvements of neutrinos detection technology. BOREXINO represents the most advanced geoneutrino detector in Italy and it is located inside INFN laboratories in Gran Sasso (LNGS) mount's heart. The counting of BOREXINO arrivals is still low, then we have time to refine theoretical estimates of global geoneutrinos flow. A mathematical law relates geoneutrinos flow density in a generic fixed point of Earth's surface to radio-nuclides bulk mass and distribution within the Earth volume (Mantovani *et al.*, 2003). We deal with the inverse problem, that is, we are collecting geoneutrinos flow data and want to derive radio-nuclides terrestrial distribution from them, and then we will be able to check the BSE model using geoneutrinos data. This will be (or not!) the decisive proof of geochemical and petrological-based models validity. The global model of radio-nuclides abundances that we propose here is necessarily approximated. Starting from the mantle, we considered it as the sum of two concentric, overlapping and homogeneous spherical shelves, separated from the 670 km depth discontinuity. A major geological complexity is shown by the crust: its contribution to the global geoneutrinos flow is very important and strongly affected from the abundances variability. We subdivided the bulk crust in many cells of prismatic shape, having a superficial area of 2x2 degrees and depth corresponding to the local Moho mean depth. Within each cell, three main crustal sub-divisions were considered, following the crustal model proposed by Wedephol (1995): Sedimentary Cover – SC, Upper Crust – UC, and Lower Crust – LC. Tectonic structure is usually ignored in order to simplify the model, except for the Grans Sasso's cell (where BOREXINO is). This cell alone produces in fact about 25% of the whole global geoneutrinos flow and is also the cell where the best accuracy in abundances is necessary. The main aim of this thesis is to estimate the mean Th and U (K geoneutrinos are not revealed by BOREXINO) contents for each crust layers of this cell. The average Th and U abundances in the crustal layers of the adjacent cells were assumed to be constant, and derived from the global geochemical literature (Mantovani *et al.*, 2003).

In order to define the geological structure of BOREXINO cell we used the seismic reflection profiles published in the CROP Volume (Finetti, 2005), and integrated them with all data available from wells located in the investigated area. We used Go-Cad software to create a digital model of the crustal tectonic structure of the cell, limiting the model to the main geological features (crustal thrusts and crustal layers thicknesses).

The great variety of rock lithotypes present in the area were grouped, based on the concept of "Radio-nuclidic Reservoirs" thus reducing also the sampling to carry out in the field. Assuming that each Reservoir is characterized by a homogeneous radio-nuclides composition, four different Reservoirs were defined within the SC based on the geological map of Vezzani & Ghisetti (1998): 1) pure carbonates and sulphates, 2) anoxic carbonates, 3) marly carbonates, 4) silicoclastic sediments. Whole-rock major and trace element analyses (particularly Th, U and K) were carried out on the most representative lithologies within each reservoir and their arithmetic mean assigned to the Reservoir. Analyses were carried out by XRF, ICP-MS and γ-spectrometry at the Department of Earth Sciences of Ferrara University and INFN Laboratories of LNGS.

Basement rocks do not outcrop in the investigated area, but they do outcrop in the Valsugana and Ivrea-Verbano zones, which may be considered representative of the crustal rocks beneath the Gran Sasso. Thus a systematic sampling of these rocks was carried out and samples were analyzed with the above described analytical techniques. Based on petrographical and geochemical features, one felsic and one mafic Reservoirs were defined both for UC and LC. The relative proportions between felsic and mafic lithotypes within UC were estimated on propagation of the seismic waves. On the base of published seismic refraction profiles available for the cell area (Ponziani *et al.*, 1995), the "velocity structure" of the deep crust was reconstructed. The measured values were compared with three different sets of ultrasonic experiments data performed on various rock samples from standard to high P/T conditions (Holbrook *et al.*, 1992; Christensen & Mooney, 1995; Weiss *et al.*, 1999). In this way it would be possible to compare lithology with seismic wave propagation velocity. Due to local perturbations of the geothermal gradient in the Thyrrenian side of the cell, only the Adriatic portion of cell was considered. This is evident, for example, for the Adriatic upper mantle (UM) which records velocity of 7.9-8.0 km/sec, in good agreement with the sub-continental worldwide upper mantle (Christensen & Mooney, 1995), whereas Thyrrenian UM velocity is rather lower (7.7 km/sec).

The SC layer shows a refraction profile velocity varying between 4.8 and 5.2 km/sec. Below this layer, from 6 to 35 km, velocity ranges from 6.0 to 6.7 km/sec. Based on the seismic profile the UC/LC transition can be identified at the 6.5-6.7 km/sec discontinuity (mean depth of 25 km), where the granulite facies is probably becoming predominant. Within the UC an uppermost "low velocity layer, LVUC" (mean velocity 6.1 km/sec), and a lowermost "high velocity layer, HVUC" (mean velocity 6.5 km/sec) can be clearly identified. Comparing these velocities with the ultrasonic data, a 100% felsic composition for LVUC and a 40/60 ratio of felsic/mafic rocks for HVUC can be put forward. As the two UC layers have a similar thickness in the refraction profile, a final bulk UC ratio of 70/30 of felsic/mafic rocks can be obtained, which is systematically lower than other similar literature estimates (Christensen & Mooney, 1995; Wedephol, 1995; Gao *et al.*, 1998).

Due to the large spread of ultrasonic data for lithotypes at LC level, this kind of approach cannot be used for evaluating the felsic/mafic rock proportions within LC. Alternatively the heat flow data can provide some useful information. A map of the superficial heat flow distribution of the Alpine-Apenninic system has been recently published (Della Vedova *et al.*, 2001). For the Gran Sasso area, a mean heat flow of 35 mW/m^2 is measured, which, according to Della Vedova *et al.* (2001) could be as high as 50-60 mW/m^2 if the cooling effect of the water circulation in the SC is removed.

Considering the heat production from elements abundances of the SC (Th 1.86-8.31 ppm; U 0.78-2.28 ppm), the bulk SC contribution to the heat flow may vary from 3 to 13 mW/m^2. Analogously, the heat flow contribution of the UC can be obtained (16 mW/m^2) assuming mean abundance values of

7.90 and 1.54 ppm of Th and U respectively. The mantle contribution to the heat flow, 25 mW/m^2, was derived from the conductive geotherm recorded from lithospheric mantle xenoliths of the Mediterranean area (Beccaluva *et al.*, 2005).

In a ideally nearly conductive steady-state thermal regime, the superficial heat flow should be the sum of mantle heat flow and the radiogenic heat flow produced by the three different crustal layers.

Thus, by simple subtraction, the contribution of LC to the heat flow can be obtained and, by consequence, the Th, U (and K) abundances (Th 4.83; U 0.38), which correspond to a felsic/mafic rock ratio of 70/30.

At this point the total amount of Th and U abundances in the Gran Sasso continental crust can be evaluated, and the theoretical geoneutrinos flow at BOREXINO location calculated with more precision. This will improve Mantovani *et al.* (2003) global crustal model at local level. Our radio-nuclides estimates for the Central Appenines crust appear to be much lower than global crustal estimation from the literature (Wedephol, 1995; Rudnick & Fountain, 1995; Christensen & Mooney, 1995) due to the high proportion (37%) of nearly pure carbonates in the SC.

REFERENCES

Beccaluva, L., Bianchini, G., Bonadiman, C., Coltorti, M., Macciotta, G., Siena, F., Vaccaro, C. (2005): Within-plate Cenozoic volcanism and lithospheric mantle evolution in the western-central mediterranean area. *In*: "CROP Project: Deep seismic exploration of the central Mediterranean and Italy" I.R. Finetti, ed. Elsevier, Amsterdam, 641-664.

Christensen, N.I. & Mooney, W.D. (1995): Seismic velocity structure and composition of the continental crust: global view. *J. Geophys. Res.*, **100-B6**, 9761-9788.

Della Vedova, B., Bellani, S., Pellis, G., Squarci, P. (2001): Deep temperatures and surface heat flow distribution. *In*: "Anatomy of an orogen, the Apennines and adjacent Mediterranean basins", G.B. Vai & I.P. Martini, eds. Kluwer, Dordrecht, 65-76.

Finetti. I.R. (2005): CROP Project: Deep seismic exploration of the central Mediterranean and Italy. Elsevier, Amsterdam, 794 p.

Gao, S., Luo, T.-C., Zhang, B.-R., Zhang, H.-F., Han, Y.-W., Zhao, Z.-D., Hu, Y.-K. (1998): Chemical composition of the continental crust as revealed by studies in East China. *Geochim. Cosmochim. Acta*, **62**, 1959-1975.

Holbrook, W.S., Mooney, W.D., Christensen, N.I. (1992): The seismic velocity structure of the deep continental crust. *In*: "Lower continental crust", D.M. Fountain, R. Arculus & R. Kay, eds. Elsevier, Amsterdam, 1-43.

Mantovani, F., Carmignani, L., Fiorentini, G., Lissia, M. (2003): Antineutrinos from Earth: A reference model and its uncertainties. *Phys. Rev.*, **D69**, 013001.

McDonough, W.F., Sun, S.S., Ringwood, A.E., Jagoutz, E., Hofmann, A.W. (1992): K, Rb, and Cs in the Earth and Moon and the evolution of the Earth's mantle. *Geochim. Cosmochim. Acta,* **56**, 1001-1012.

Palme, H. & O'Neill, H.S.C. (2003): Cosmochemical estimates of mantle composition. *In*: "The mantle and core", R.W. Carlson, ed. Elsevier-Pergamon, Oxford, 1-38.

Ponziani, F., De Franco, R., Minelli, G., Biella, G., Federico, C., Pialli, G. (1995): Crustal shortening and duplication of the Moho in the Northern Apennines; a view from seismic refraction data. *Tectonophys.* **252**, 391-418.

Vezzani, L. & Ghisetti, F. (1998): Carta geologica dell'Abruzzo, scala 1:100.000. S.EL.CA., Firenze. (1998).

Wedepohl, K.H. (1995): The composition of the continental crust. *Geochim. Cosmochim. Acta*, **59**, 1217-1239.

Weiss, T., Siegesmund, S., Rabbel, W., Bohlen, T., Pohl, M. (1999): Seismic velocities and anisotropy of the lower continental crust: a review. *Pure Appl. Geophys.*, **156**, 97-122.