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Crustal Deformation at the Friuli Area from Discrete and Continuous Geodetic Prediction Tecniques

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Summary. — An analysis of maximum shear strain is carried out at the seismic zone of Friuli, North Italy, using triangulation results. Maximum shear strain values are predicted through collocation and compared with patterns from classical techniques. The importance of applying bidimensional filters for isolating main deformation features is demonstrated.

DEFORMAZIONI DELLA CROSTA NELLA ZONA DEL FRIULI MEDIATE TECNICHE GEODETICHE DI PREVISIONE SIA DISCRETE CHE CONTINUE.

Sommario. — Viene effettuata un'analisi della massima deformazione da taglio nella zona sismica del Friuli, Italia Settentrionale, utilizzando risultati di triangolazioni. I valori di massima deformazione da taglio vengono previsti mediante la collocazione e confrontati con l'andamento ottenuto con tecniche classiche. Si dimostra l'importanza dell'applicazione di filtri bidimensionali per isolare le caratteristiche principali delle deformazioni.

DÉFORMATION DE LA CROÛTE DANS LA ZONE DE FRIULI PAR DES TECHNIQUES GÉODÉSIQUES DE PRÉDICTION DISCRÈTES ET CONTINUES.

Résumé. — On analyse la déformation en cisaillement maximum dans la zone sismique de Friuli (Italie du Nord) en utilisant les résultats de la triangulation. On fait la prédiction des valeurs

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de la déformation ci-dessus à l'aide de la méthode de la collocation et on compare les résultats à ceux des techniques classiques. On montre l'importance des filtres bidimentionels pour la détection des caractéristiques principales de la déformation.

ERFASSUNG VON ERDKRUSTE DEFORMATIONEN IN DEM GEBIET VON FRIULI DURCH DISKRETE UND KONTINUERLICHE GEODÄTISCHE PRÄDIKTION.

Zusammenfassung. — Eine Analyse der maximalen Deformationen aus Schubbeanspruchung wurde in der seismischen Zone von Friuli in Norditalien an Hand von trigonometrischen Ergebnissen durchgeführt. Die Maximalwerte dieser Deformationen werden durch Kollokation bestimmt und mit denjenigen aus den klassischen Berechnungsverfahren verglichen. Die Bedeutung der Auswendung zwei-dimensionaler Filter zur Aufdeckung wichtiger Deformationsmerkmale werden aufgezeigt.

INTRODUCTION

An application of mathematical treatment of repeated triangulation results at the seismic area of Friuli, North Italy, for the extraction of crustal strains is presented, following the techniques described in Dermanis et al. 1981.

Two methods of analysis are used and compared, the classical discrete approach utilizing triangular finite elements and continuous approaches based on modern interpolation techniques. Details on the above techniques are given in Livieratos 1980 and Dermanis et al. 1981.

The data used are those of the two Friuli triangulations namely the 1948 triangulation and the one in 1977 just after the 1976 great Friuli earthquake, computed by Bencini (I.G.M.-RG 1978).

Geophysical interpretation of the results obtained here, is beyond the scope of the present work. Nevertheless our results are in significant agreement with other geophysical evidences, see, e.g., Giorgetti 1976 and Lyon-Caen 1980.

DATA TREATMENT

The 1977 Friuli plane triangulation includes 19 points common with the 1948 triangulation. Two of these points outside the main seismic zone have coordinates fixed to their 1948 values and therefore cordinate differences are available for the remaining 17 points. Both triangulations have been adjusted according to Bencini 1967.

Our first concern was to check the validity of the assumption that the two distant fixed points are not affected by deformations. For this purpose the new coordinate set has been transformed by a similarity transformation using the program TRANSF (Dermanis and Rossikopoulos 1981). This transformation leads to an optimal fitting between new and old coordinates thus filtering out any common translation, rotation and scale alteration, which are not really present in the original data. The optimal transformation parameters were found to be

$$\Delta x = -10.9 \text{ cm}$$

$$\Delta y = 17.4 \text{ cm}$$

$$\Delta \omega = 1.^{cc}17$$

$$\Delta \mu = -0.27 \times 10^{-6}$$

where Δx, Δy are the components of parallel translation, $\Delta\omega$ and $\Delta\mu$ the rotation and scale alteration respectively.

In order to focus in the main seismic area 9 points were selected within the area and the similarity transformation has been again applied. The results

$$\Delta x = 13.5 \text{ cm}$$

$$\Delta y = -97.1 \text{ cm}$$

$$\Delta\omega = -7.^{cc}49$$

$$\Delta\mu = 3.53 \times 10^{-6}$$

are larger than those of the 19-point transformation.

Being primarily interested in the computation of the maximum shear strain (γ) -pattern, it must be noted that the choice of points to be held fixed has limited effect on the derived γ-values. Indeed, as shown by Dermanis 1981, the maximum shear strain values are affected only by scale alteration and not by the other similarity transformation parameters. A different choice of fixed points would lead to γ values which would differ only by a common scale factor, as far as the number of fixed points is always the minimal necessary for frame definition; the γ-pattern however will remain unaltered.

For the well known finite element method the program CRUSTR (Livieratos and Tokmakidis 1981) has been used, while continuous predictions of γ were obtained based on collocation principles, where the planar field of displacements are treated as isotropic signal functions with exponential covariances.

Initially the intermediate vectors **a**, **b** are computed by means of

$$\mathbf{a} = \mathbf{K}^{-1}\,\mathbf{u}$$
$$\mathbf{b} = \mathbf{K}^{-1}\,\mathbf{v} \qquad (1)$$

where **u**, **v** are vectors containing the x and y displacement components respectively of the n common triangulation points, and **K** is a matrix with elements

$$K_{ij} = e^{-\sigma^2 r_{ij}^2} \qquad (2)$$

r_{ij} being the distance between points P_i and P_j.

The γ-values at any desired point P are finally computed from

$$\gamma = \sqrt{\gamma_1^2 + \gamma_2^2} \qquad (3)$$

where

$$\begin{aligned}\gamma_1 &= 2\sigma^2 \sum_i \{e^{-\sigma^2 r_i^2} [b_i(y - y_i) - a_i(x - x_i)]\} \\ \gamma_2 &= 2\sigma^2 \sum_i \{e^{-\sigma^2 r_i^2} [a_i(y - y_i) + b_i(x - x_i)]\}\end{aligned} \qquad (4)$$

r_i being the distance between points P and P_i, x, y the plane coordinates of P and x_i, y_i those of P_i.

The parameter σ in (2) is computed from

$$\sigma^2 = \frac{\ln 2}{R^2} \qquad (5)$$

where R is chosen to be of the same order of magnitude as the mean separation of adjacent triangulation points.

In order to isolate secondary high frequency effects and to reveal the main deformation pattern an a posteriori smoothing low pass filtering of the two dimensional power spectrum of the γ function obtained by collocation has been applied. For this purpose the LIZA algorithm (Livieratos and Zadro 1981) for two dimensional digital isotropic filterings has been applied.

RESULTS

For both the 9-point and 19-point sets of transformed displacement collocation prediction has been applied with various choices of covariance functions. In all solutions exponential covariances of type (2) have been used varying with respect to the R parameter (see (5)). For choices in the neighbourhood of $R = 4$ km which is close to the mean separation of adjacent triangulation point, the results are always independent of the choice of the covariance function.

In Fig. 1 the γ isarithmic curves predicted from the displacement at 19 points using exact collocation with $R = 4$ km are shown. Fig. 2 shows the same γ isarithmic curves as predicted from the displacements at 9 points only. The two γ patterns are almost identical. This shows that displacements of distant points have a negligible contribution to the γ pattern at the central epicentric area of the 9 points. Therefore one could say, with due caution of course, that analysis of maximum shear strain could be carried out utilizing only displacements at the very area of interest.

Recalling the transformation parameters we observe that in the case of 19 points their magnitudes are insignificant, thus justifying the particular choice of fixed points in the adjustment of the triangulation. The transformation parameters for the 9 points of the central area are much larger since they reflect to a certain extent the common deformation of the area points with respect to the surrounding area.

In order to isolate the main trend of the γ pattern a low pass bidimensional isotropic filter has been applied to the results of Fig. 2. Fig. 3 shows the filtered pattern after a low pass filter cutting off all wavelengths below 8 km. It is immediately seen that the main feature of concentration of maximum shear strain remains unfiltered, while all secondary high frequency features disappear. In fact Fig. 4 shows those eliminated high frequency features. The γ pattern of Fig. 4 has been obtained by applying a high pass filter cutting off all wavelenghts over 8 km.

In the filtered pattern of Fig. 4, it can be noticed that high frequency variations prevail in the N-S direction. In Fig. 5 N-S profiles passing through the point of maximum γ concentration (Fig. 3) are shown. Finally Fig. 6 shows E-W γ profiles following the orientation of the Friuli fault. In terms of absolute γ values the predicted maximum is larger in the case of collocation compared to the finite element method, while the filtered maximum value lies in-between.

From this analysis it comes out that absolute γ values depend on the perdiction method used while γ patterns do not. Therefore one should look in the γ pattern for concentration features (cf. Livieratos 1978, p. 28) rather than on the magnitude of γ within the examined area.

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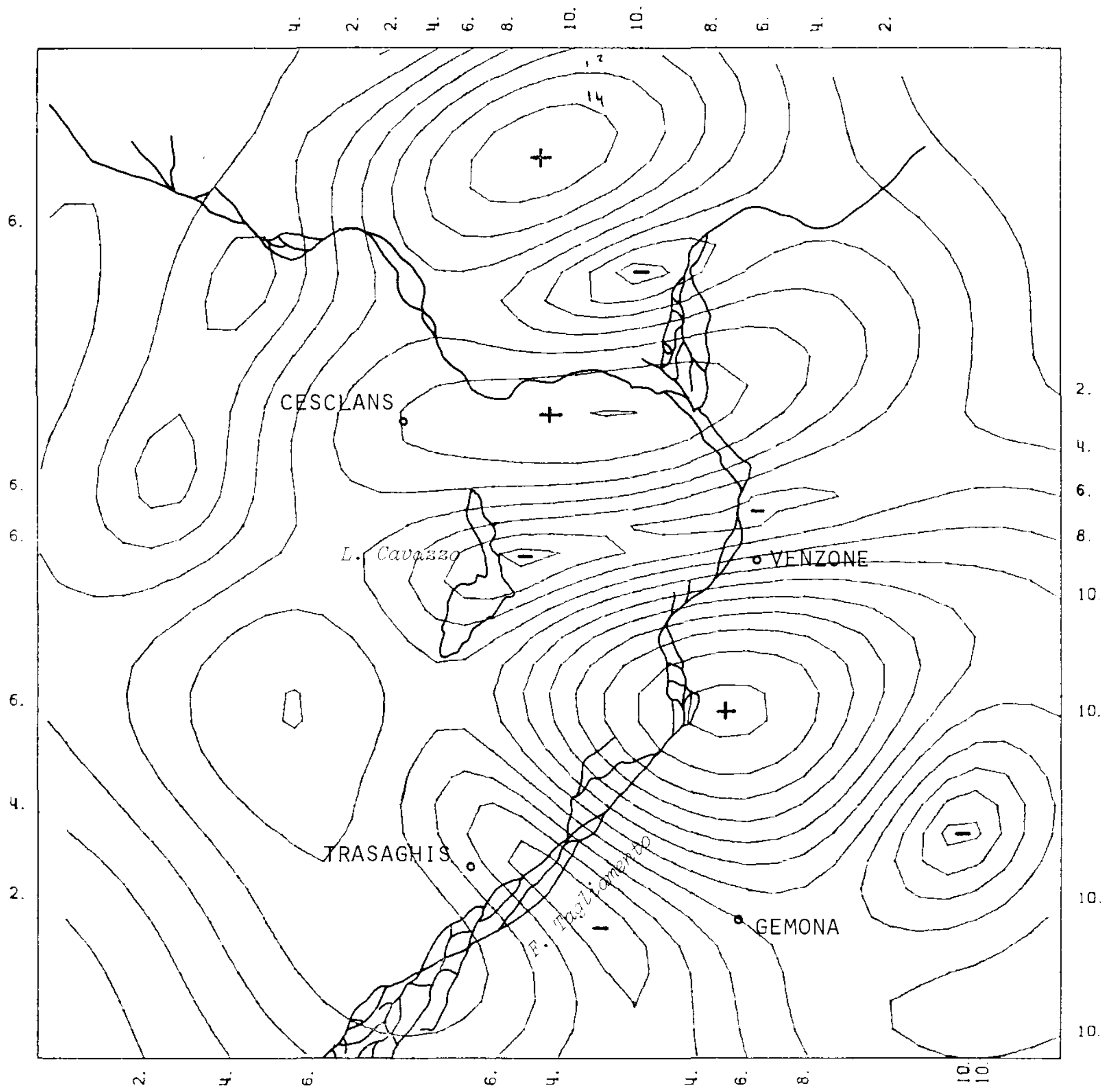

Fig. 1. — γ-values ($\times 10^5$) from 19 points using collocation ($R = 4$ km)

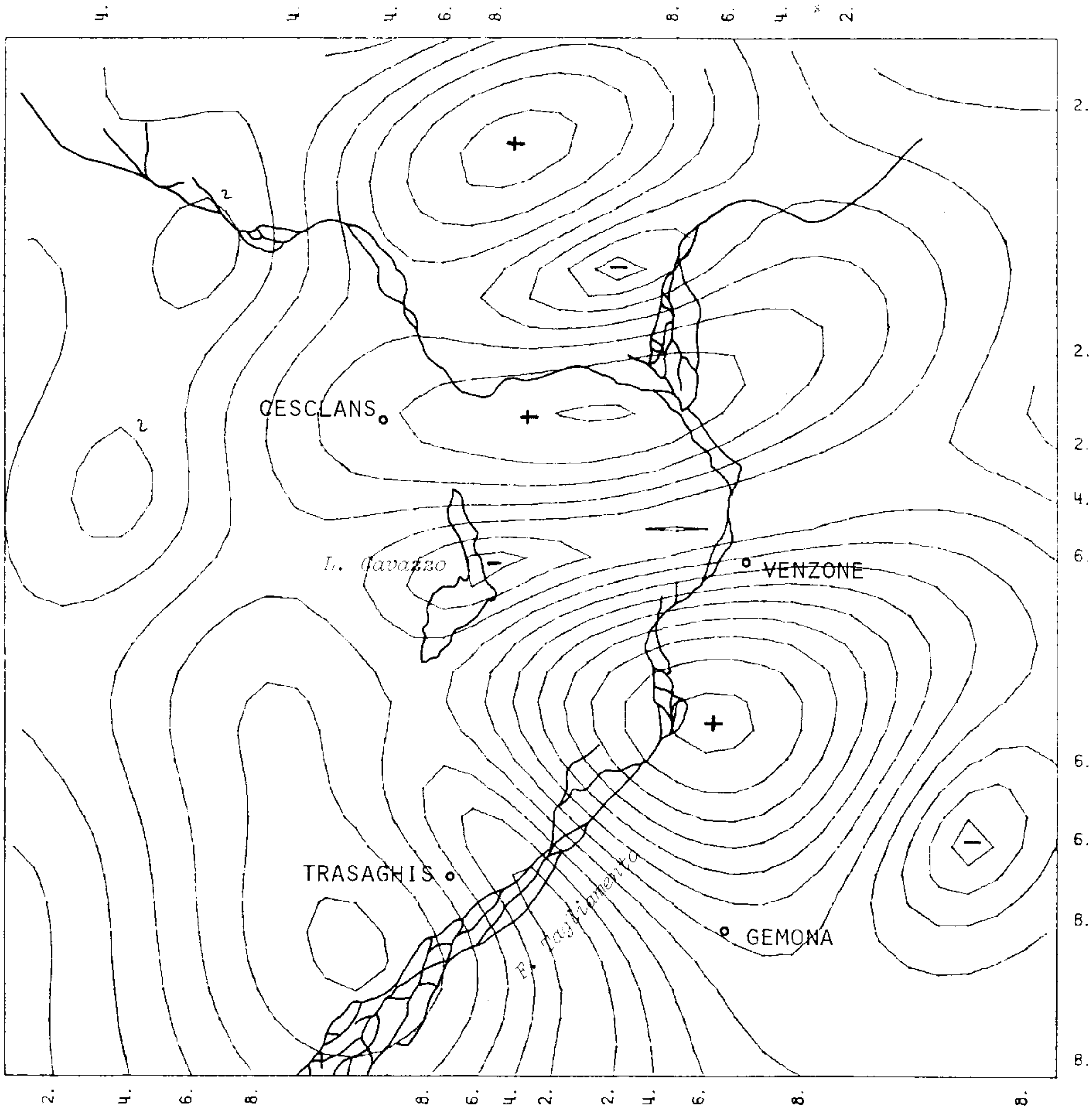

Fig. 2. — γ-values (× 10^5) from 9 points using collocation (R = 4 km)

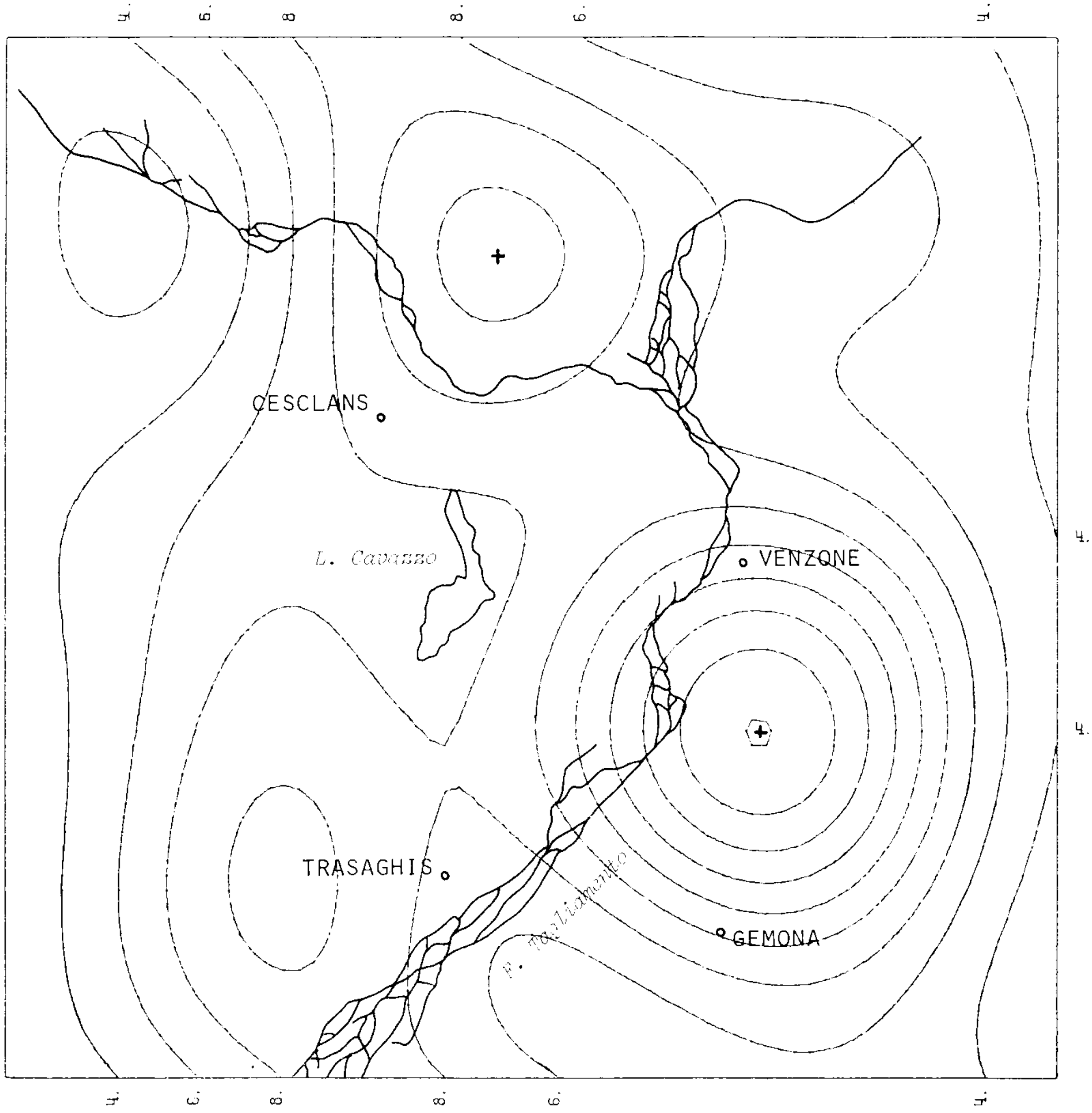

Fig. 3. — γ-values ($\times 10^5$) after 8 km low pass filtering of Fig. 2 values

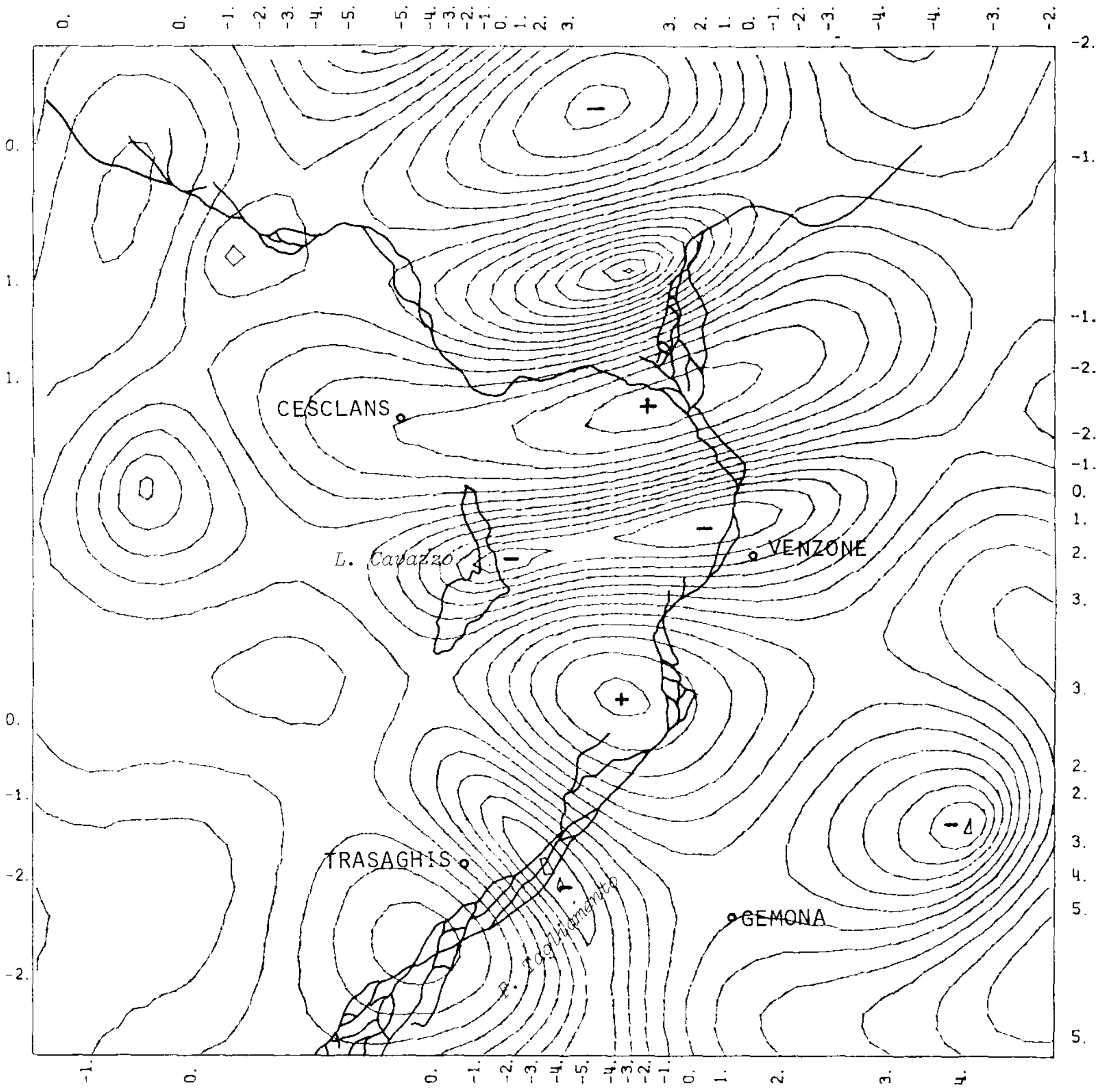

Fig. 4. – γ-values ($\times 10^5$) after 8 km high pass filtering of Fig. 2 values

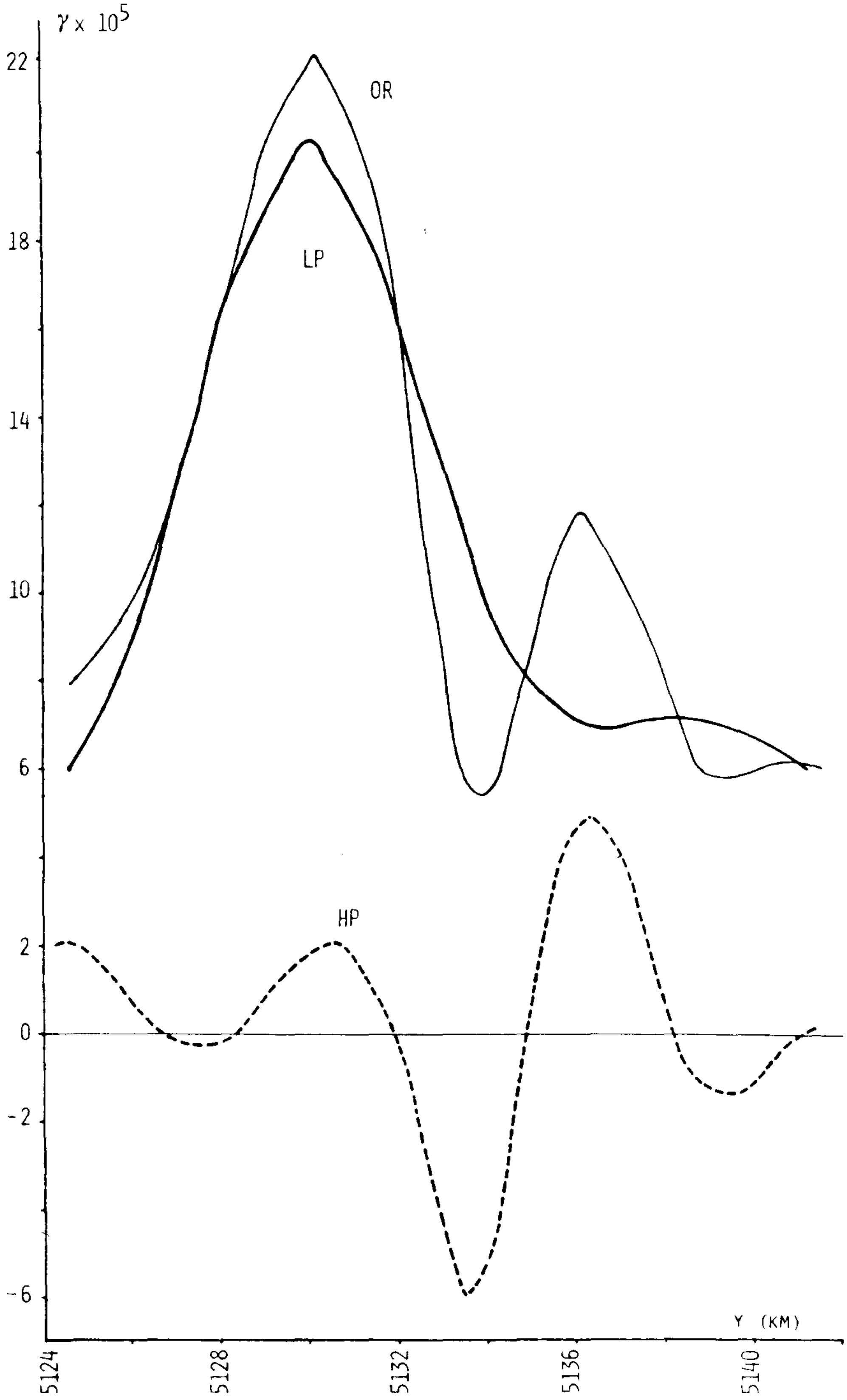

Fig. 5. — S-N γ-profile (OR = original values, LP = values after low pass filtering, HP = values after high pass filtering)

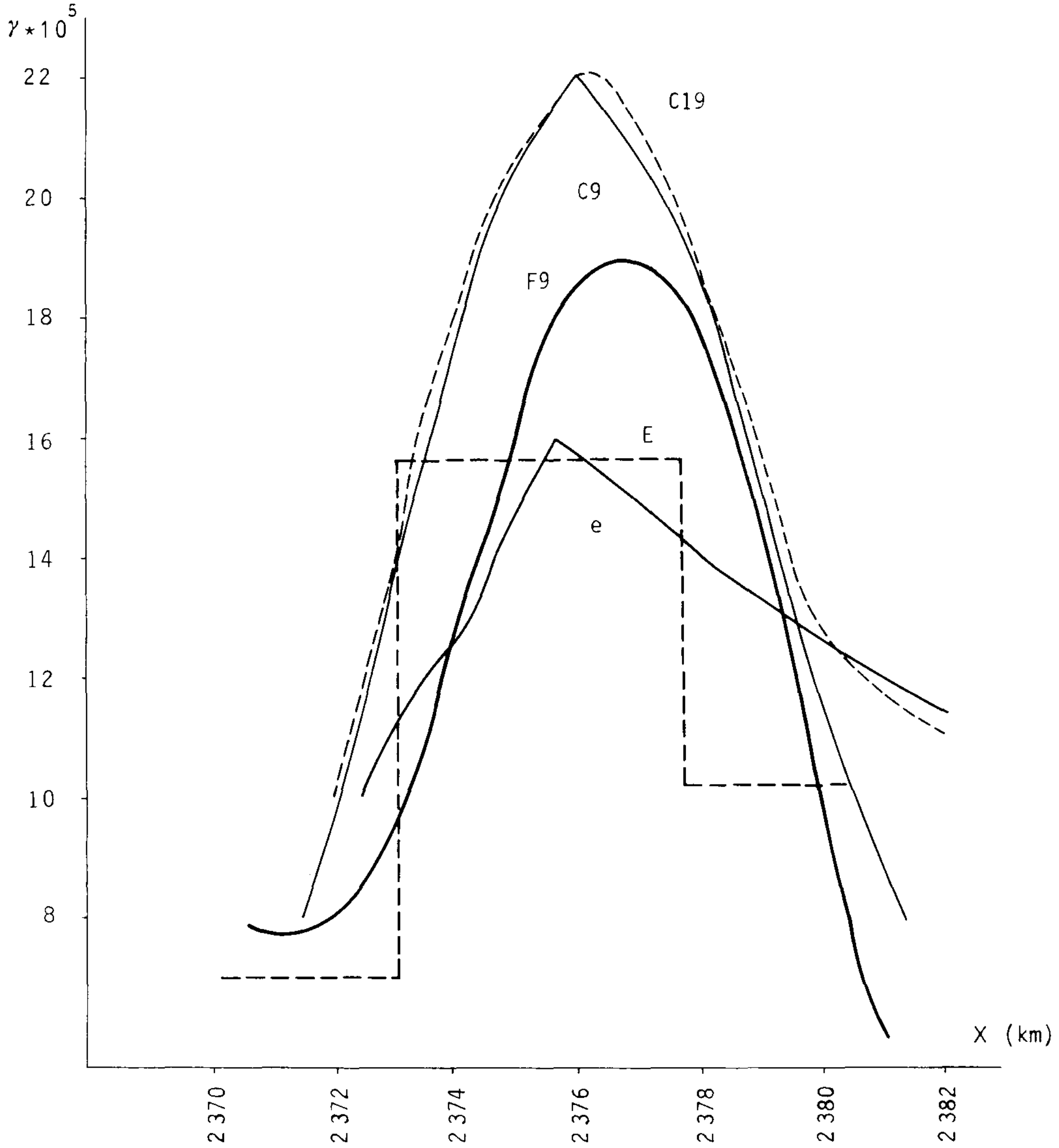

Fig. 6. — E-W γ-profile (C19 = collocation, 19-points, C9 = collocation 9-points, F = values after low pass filtering, E = values from finite element method, e = interpolated values from finite element method)