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UPLIFT MODEL BY TREND ANALYSIS OF AN APENNINE REGION LYING SOUTH OF THE LIMA RIVER (Northern Tuscany) (***)

ABSTRACT: BARTOLINI C. & NISHIWAKI N., *Uplift model by trend analysis of an Apennine region lying South of the Lima River (Northern Tuscany)* (IT ISSN 0084-8948, 1985).

Trend surface analysis of the upland surfaces lying in a restricted area of the Northern Apennines was carried out in order to obtain a model of the Tectonics which affected these paleoforms since the middle Pleistocene.

Two main components can be observed: 1) a meridian, South pitching tilted regional uplift which is well shown by the first order trend; 2) block-like movements, picked, to a certain extent, by second order trend.

RESUMÉ: BARTOLINI C. & NISHIWAKI N., *Modèle de soulèvement par l'analyse de tendence d'une région Apennine au Sud du Fleuve Lima en Toscane septentrionale.* (IT ISSN 0084-8948, 1985).

L'analyse de tendence des surfaces sommitales d'une portion des Apennines du Nord a été effectuée pour obtenir un modèle du soulèvement tectonique qui a affecté la région depuis le Pleistocène moyen.

Deux composantes peuvent être soulignées dans le mouvement: 1) une composante régionale caracterisée par un basculement Nord-Sud, qui est très bien mis en évidence par la surface de tendence du premier ordre; 2) une fragmentation en blocs séparés par failles, partiellement mis en evidence par la surface de tendence du deuxième ordre.

RIASSUNTO: BARTOLINI C. & NISHIWAKI N., *Analisi di tendenza delle superfici sommitali di un'area appenninica situata a Sud del Fiume Lima (Toscana settentrionale)* (IT ISSN 0084-8948, 1985).

È stata eseguita l'analisi di tendenza delle superfici sommitali situate in un'area di limitata estensione dell'Appennino Settentrionale allo scopo di ottenere un modello delle deformazioni tettoniche che hanno interessato queste superfici nel Pleistocene medio-superiore.

Sono state così individuate due componenti principali: 1) basculamento meridiano a carattere regionale (con sollevamento relativo del bordo settentrionale) messo in risalto dalla superficie di tendenza del primo ordine; 2) formazione di blocchi fagliati la cui esistenza emerge, in parte, dall'elaborazione della superficie di secondo ordine.

TERMINI CHIAVE: dinamica morfologica, superficie d'erosione, regressione multipla, Appennino Settentrionale.

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INTRODUCTION

The summit areas of low-relief lying North of Lucca and Pistoia (fig. 1) had been recently investigated in detail (BARTOLINI, 1980). The evaluation of divides and rivers profiles and of the frequency distributions plots of contour lines as well as of the hypsographic curve obtained from a digital model, led to the identification of the low-relief summit areas as uplifted paleoforms.

The lack of sedimentary deposits coeval with the paleosurfaces did not allow a direct dating of their development. Weathering mottles due to iron oxides and hydroxides are common features of the summit areas bedrock. Field and laboratory studies led to assume such features as deep remnants of plinthitic soils which should antedate the uplift. The latter is recorded by a continental sequence laid along the southern border of the studied area. From the age of such sequence an early middle Pleistocene age of the uplift (ever since active) can be inferred (BARTOLINI & *alii*, 1985).

The present paper aims, through trend surface analysis of the paleosurface remnants, to an interpretation of the original morphology and of the following uplift pattern; the latter will be matched to the recent tectonic movements which are known to have occurred in the area.

THE TREND ANALYSIS

Trend surface analysis is designed to detect, by means of multiple regressions of *n* order, the regional trend in a variable mapped within an area. It can be defined as a « mathematical statement of a trend in the data values » (DOORNKAMP, 1972). The higher the order of the trend-surface, the better it will usually fit the mapped variable and the lower the deviations will be.

The goodness of fit of the trend-surface to the original data can be tested in various ways.

The basic principle is to compare the variability in the original data accounted for by the surface, to the total variability. The former may be expressed as

$$S_{trend} = \Sigma \, (Z_{obs} - Z_{calc})^2$$

which, for each polynomial equation representing each surface, is kept to minimum since the trend surface is fitted by least-squares method. The latter is expressed as

$$S_{data} = \Sigma \, (Z_{obs} - \overline{Z}_{obs})^2$$

The difference of the two is the residual deviance

$$S_{dev} = S_{data} - S_{trend}$$

The extent to which the computed trend-surface « explains » the variation in the data can be stated as the percentage reduction in the total sum of squares accounted for by the fitted surface expressed as

$$\mathrm{RSS} = 1 - \frac{S_{trend}}{S_{data}} \; 100 \,\%$$

or as the $\frac{S_{trend}}{S_{data}}$ percentage ratio known as goodness of fit.

The S_{trend} and S_{dev} function can be also utilized for an ANOVA test of the statistical significance of the trend component of the variability (HARBAUGH & MERRIAM, 1968). The number of degrees of freedom of S_{trend} is the number of terms in the trend component (m) and that of S_{dev} is the number of data points (n) minus ($m-1$).

The individual deviations of each control point from the regional trend, referred to as residuals, are interpreted as due to local factors which are brought to light after removal of the general trend. As such, the interpretation of the residuals may be even more appealing than that of the regional trend itself.

A good fit of lower order surfaces to the mapped data will prove that a regional trend actually affects the data much better than if these are fitted only by a higher order surface. In this case, in fact, local undulations inevitably affect the form of the computed surface.

COLLECTION OF ORIGINAL DATA

The studied area (fig. 1) was covered with a grid of 18096 points spaced at 200 m intervals. The Z value of each point was obtained averaging the altitude of all the digitized contour line points lying within a 200 m sided square. The summit areas of low relief (referred to, also, as upland surfaces) were reported on a map from an aerial photographic survey of the investigated area (fig. 2). The points of the original grid encompassed by the summit areas are 565. The hypsographic curve of the summit areas based on such points is shown in fig. 3. The areal distribution of the summit areas is not random, but trending instead approximately from North (where the higher altitudes are found) to South. A sur-

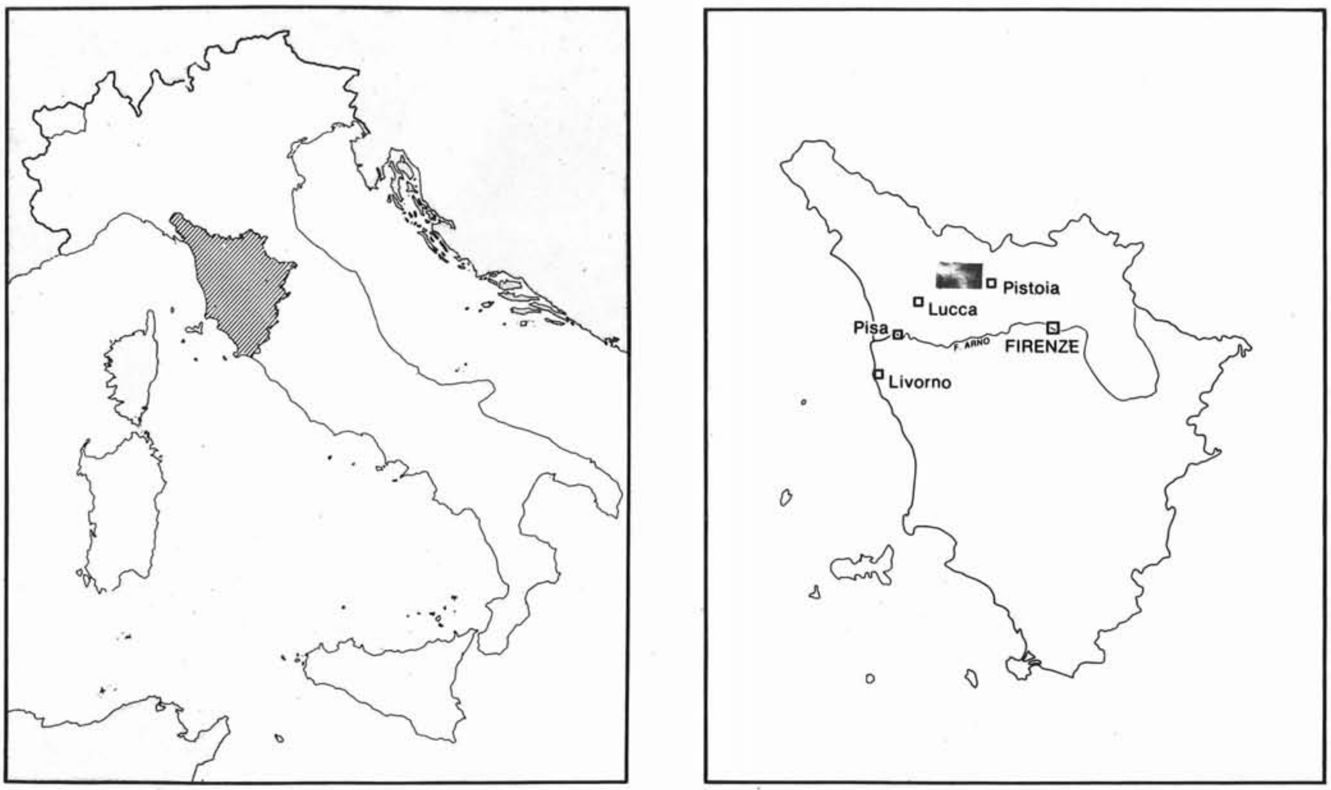

FIG. 1 - Location of the studied area.

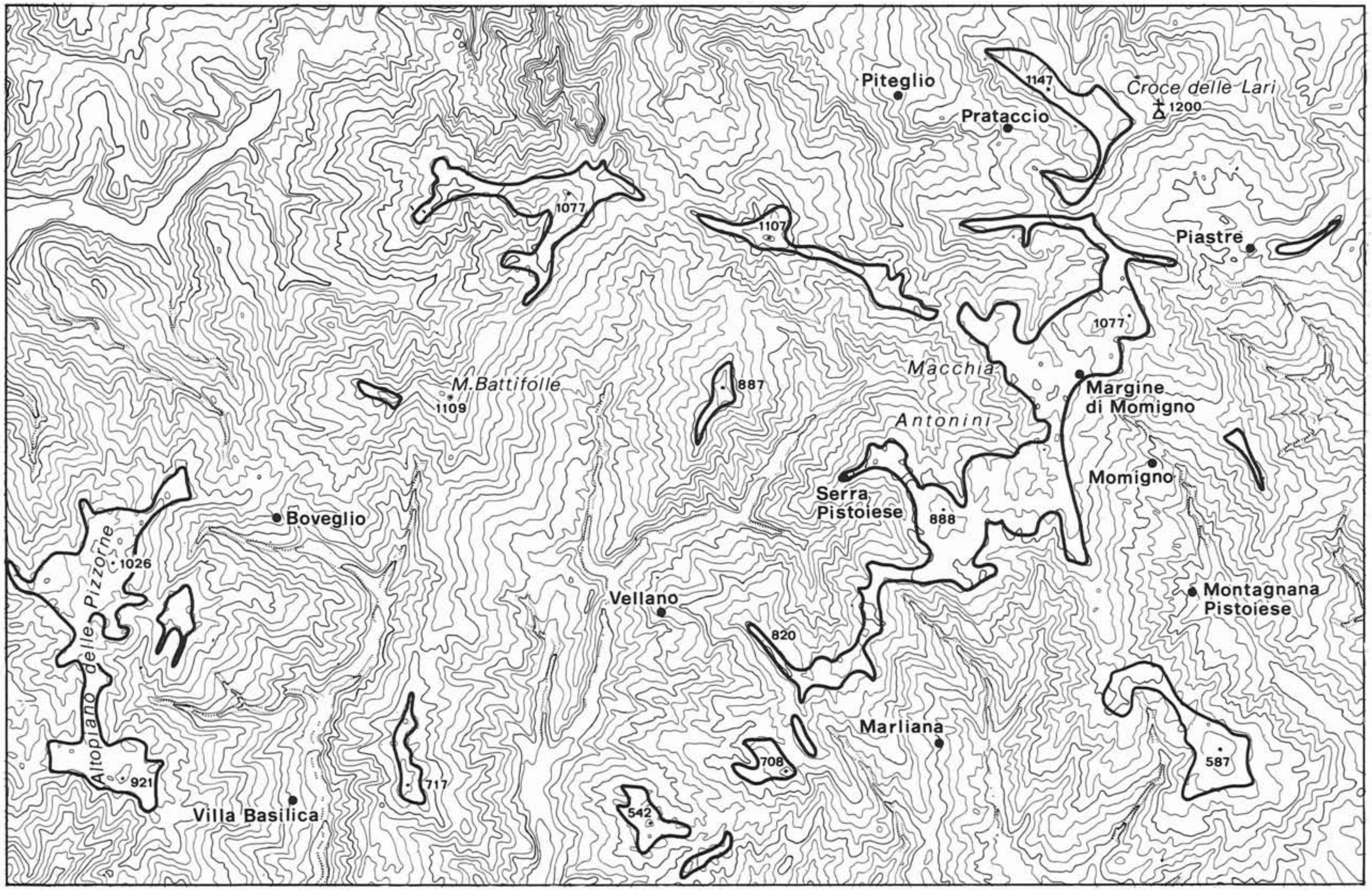

FIG. 2 - The processed area and the low relief summit aereas. Contour interval 50 m.

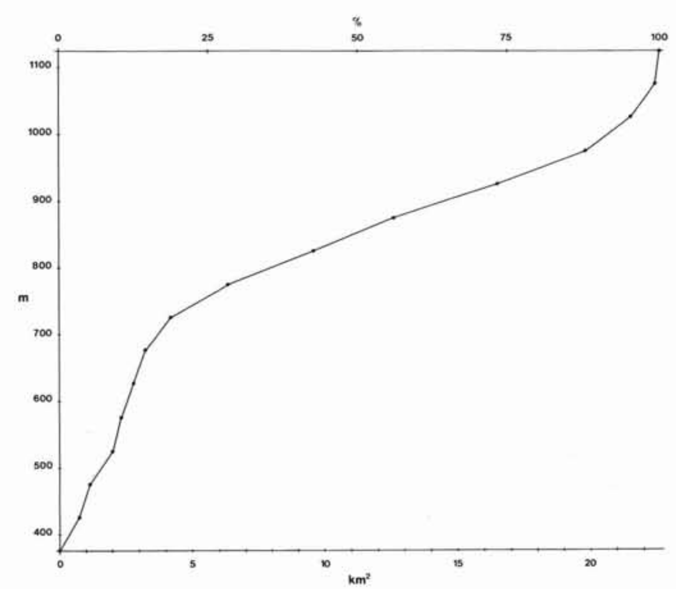

FIG. 3 - Cumulative hypsographic curve of the low relief summit areas (from BARTOLINI, 1980, redrawed).

face trend analysis was therefore devised in order to detect the actual amount of trend.

Owing to the type of data (i.e. portions of a regular grid scattered over an area) a certain amount of clustering affects the original data, which should in principle be avoided. Clustering will affect the *RSS* value especially in higher order surfaces, which, however, will not need to be taken into account in our study. As to the normality of the data (which is the other main assumption required in trend analysis) fig. 4 shows that the distribution is only slightly skewed towards the lower altitudes.

TREATMENT OF DATA

Original Gauss-Boaga coordinates of the national network, which were utilized for performing the digital model (BARTOLINI, 1980), were simplified as follows:

$$x = X - 4800000, \; y = Y - 1600000$$

SPSS (NIE & *alii*, 1975) and TSAP (YAMAMOTO & NISHIWAKI, 1975) programs were utilized to perform trend surface analysis of polynomial fitting. Data pro-

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      I
 400. * (       1)
      I
 450. ****** (      18)
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 550. ****** (      21)
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      I
 750. ********* (      31)
      I
 800. ************** (      53)
      I
 850. ********************** (      86)
      I
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      I
 950. **************************** (     108)
      I
1000. ****************** (      67)
      I
1050. *********** (      39)
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1150. ** (       5)
      I
      I.........I.........I.........I.........I.........I
      0        40        80       120       160       200
      FREQUENCY
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FIG. 4 - Frequency distribution of the original data. Figures on the vertical scale are lower limits of 50 m wide altitude classes.

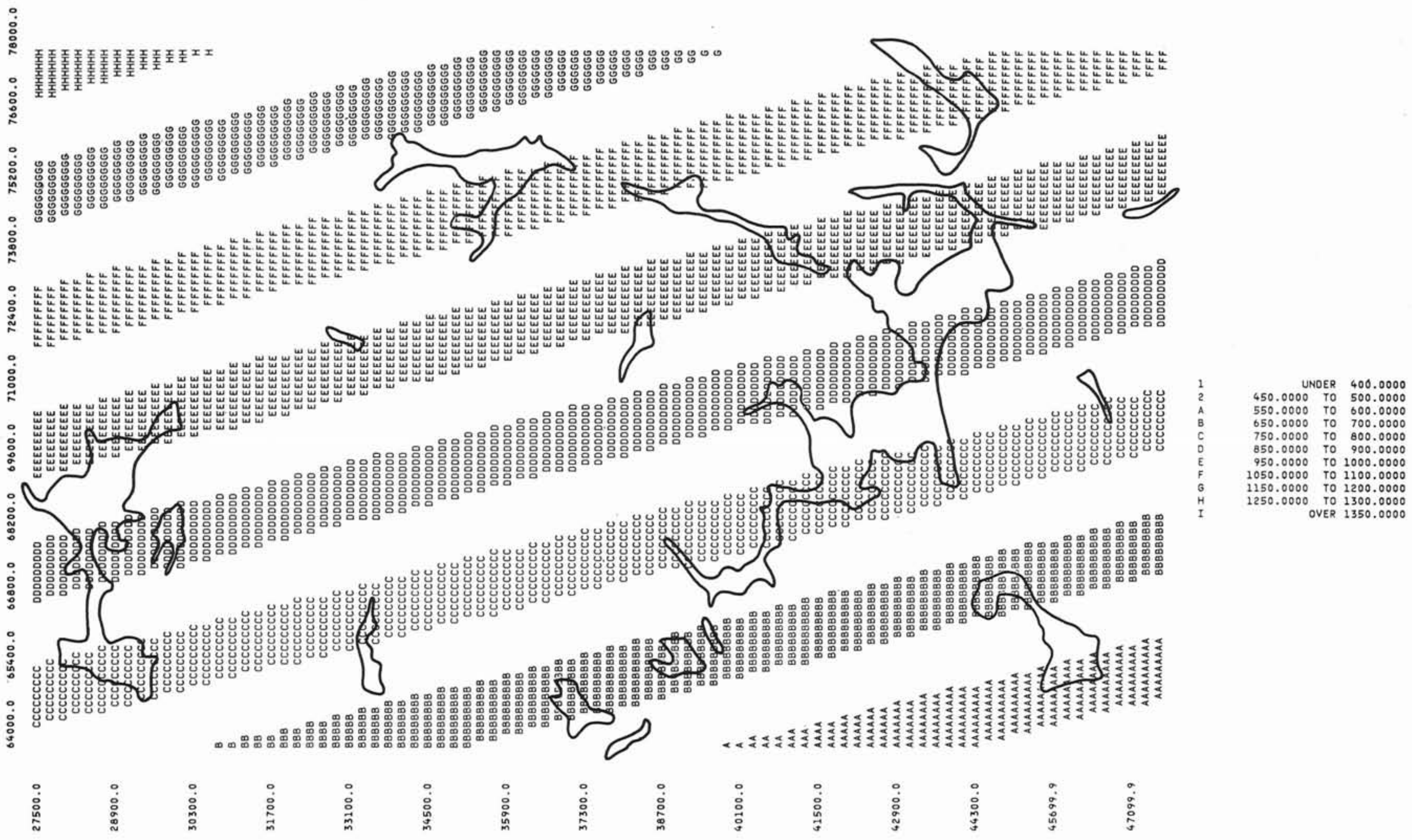

Fig. 5 - First order surface trend and location of the paleoforms over which the trend was computed.

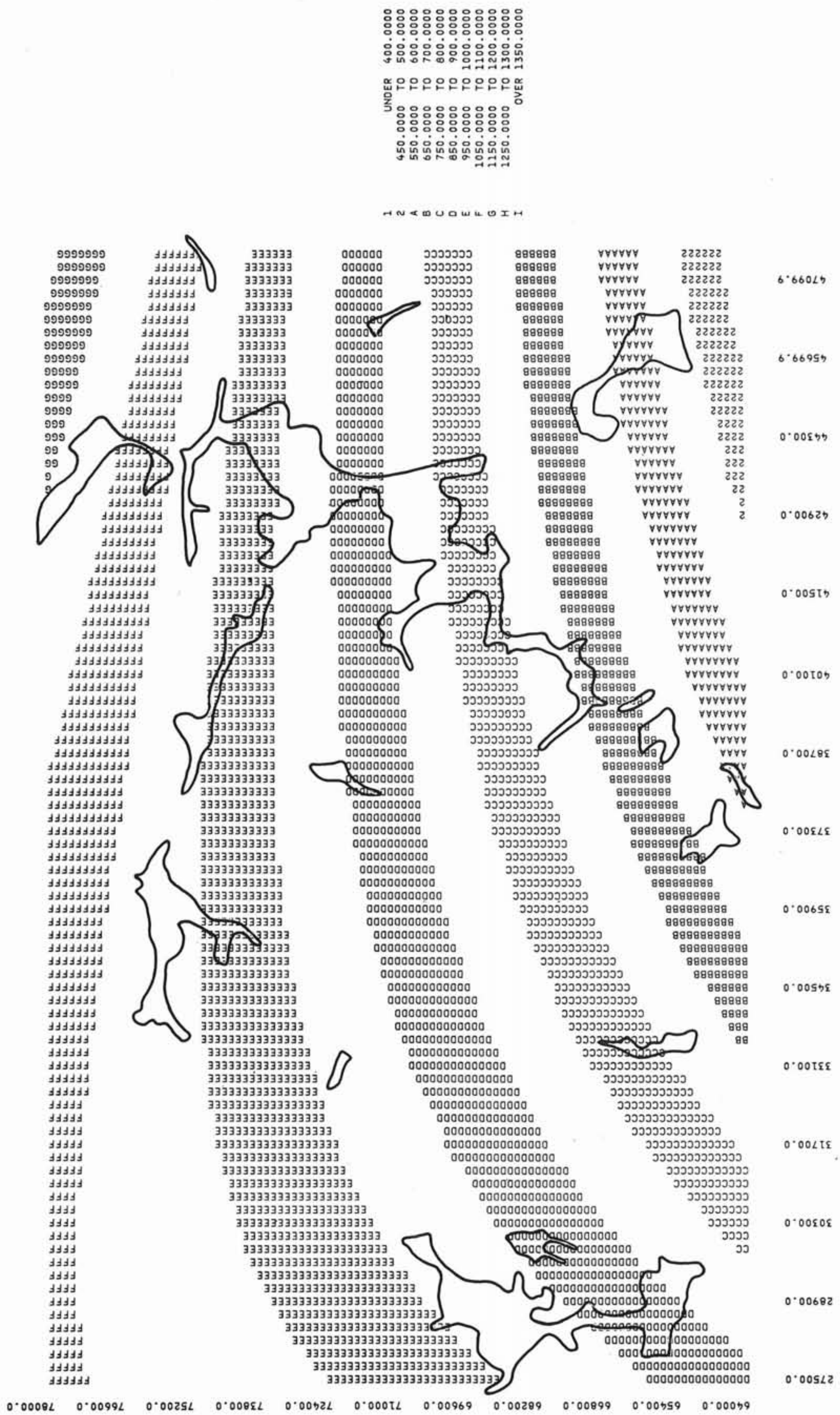

FIG. 6 - Second order surface trend.

cessing was carried out by the computer system FACOM M 380/382 at the Data Processing Center of Kyoto University.

RESULTS

The first order trend surface (fig. 5) is a plane sloping 4.4 % to the SSE. Its polynomial equation is:

$$Z = -1476.4458 + 0.039291512\,x - 0.011006456\,y$$

The total map variability, expressed as the total corrected sum of squares of the observed data is 1.397×10^7. The computed linear values have a corrected sum of squares of 9.416×10^6 and the deviations are

$$1.397 \times 10^7 - 9.416 \times 10^6 = 4.554^6$$

The linear surface accounts thus for 67.38 % of the total sum of squares of the mapped data (goodness of fit). The RSS is 32.62 %. With, respectively, 2 and 562 d.f. the F ratio is 580. The probability of obtaining a value larger than this is less than 0.1 % and the linear surface can be inferred as being real.

The second order trend surface is shown in fig. 6. The overall slope is still to the SSE. A SSW slope is shown however in the northeasterly area. Sloping is steeper in the eastern than in the western section. The equation is:

$$Z = 2745.4590 + 0.015500363\,x - 0.18859053\,y - \\ - 0.00000042114334\,x^2 + 0.0000021127544\,xy + \\ + 0.00000042062743\,y^2.$$

The corrected sum of squares is 1.0804×10^7 and the deviations are 3.166×10^6. The quadratic surface accounts, alone, for only $77.33 - 67.38 = 9.95$ percent of the total sum of squares. The RSS of the linear *plus* quadratic component is 22.67. With, respectively, 3 and 559 d.f. the F ratio between the mean square due to quadratic and of deviations from quadratic is 81 which is still highly significant. The cubic surface coefficients are very small and the contribution of this function is negligible.

It may be stated, then, that both the linear and the quadratic surface are a valid model for the uplift pattern of the studied area. The regional tectonic trend points thus to a differential uplift which is higher towards the Apennine chain axis. This statement, inasmuch as it is obvious from a geological standpoint, supports instead the basic assumption of the summit areas being remnants of a low-relief, sub-horizontal surface, close to the general base level. The former presence of a low pedemontane area in this region is supported from sub-

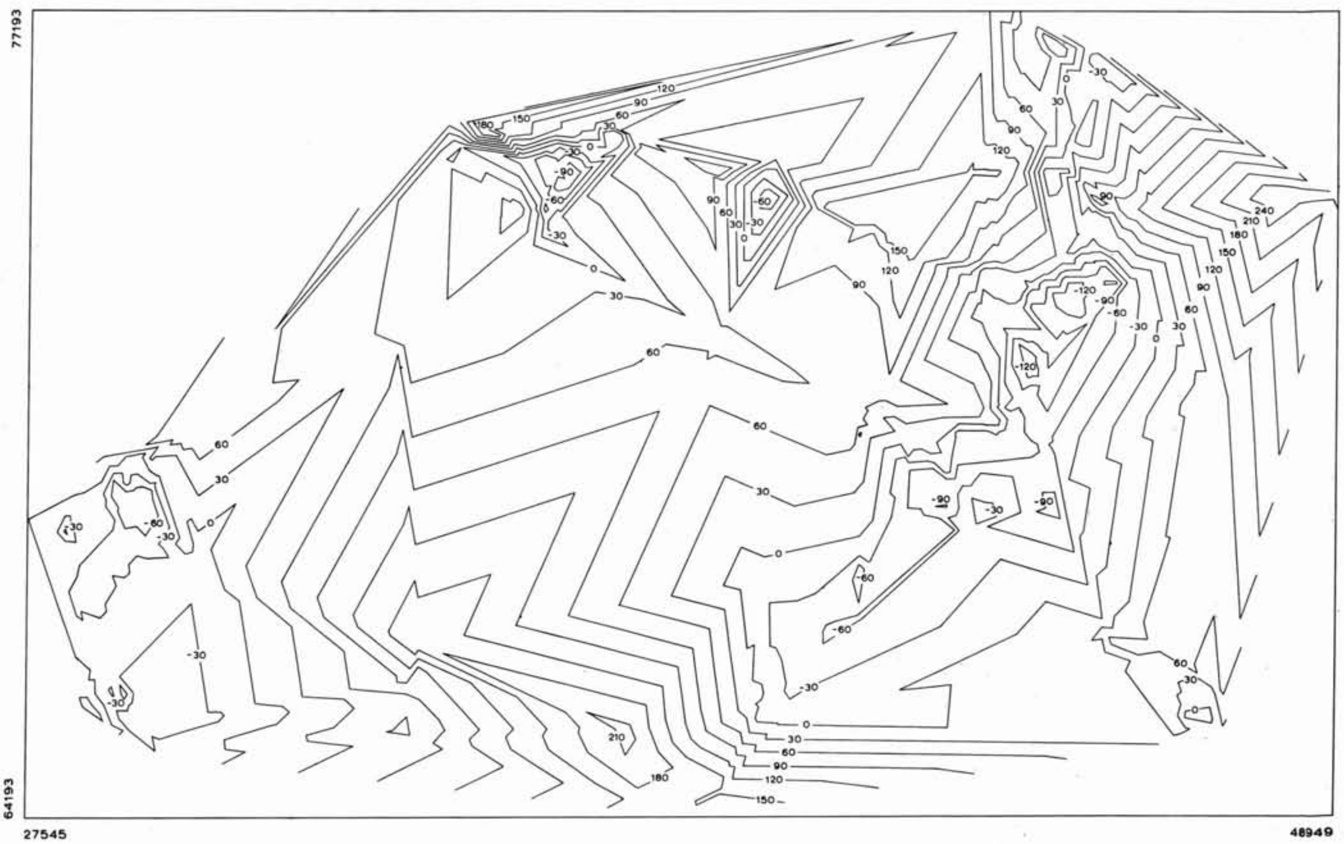

FIG. 7 - Contour line map of the deviations from the linear trend surface.

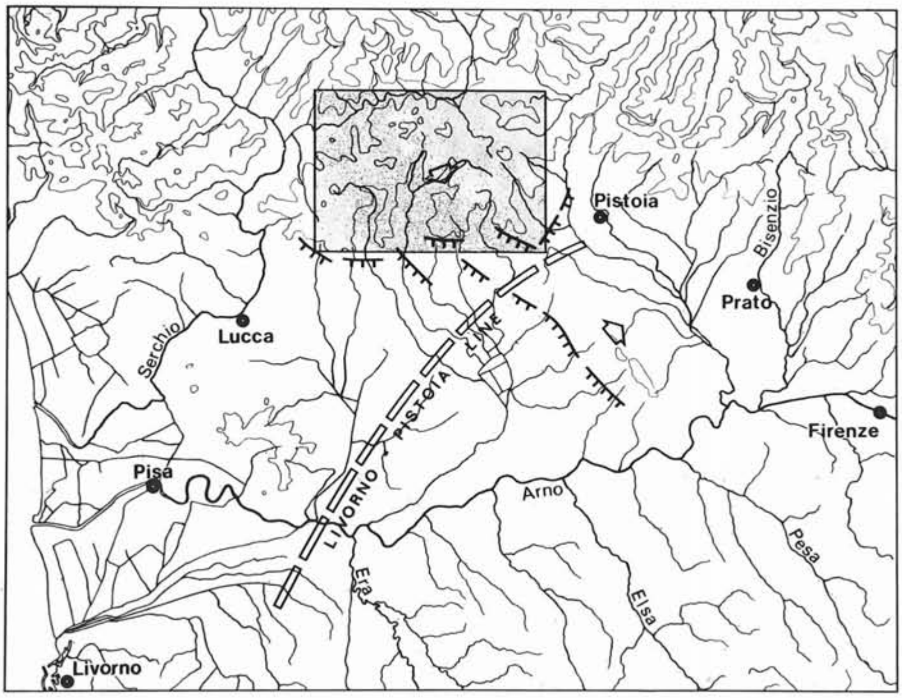

FIG. 8 - Neotectonic sketch map of the studied and surrounding areas, showing the different uplift pattern which occurred either side of the Livorno - Pistoia Line. Arrows indicate pitch of tilted uplift.

surface data which suggest that, at least until Pliocene times, the Serchio River crossed the studied area (BARTOLINI & PRANZINI, 1979). As to the origin of such surface, it can be tentatively hypothesised that a glacis extended along the present main Apennine Chain. Following the studies on Pliocene glacis of presently cold-temperate areas such as those of FINK (1961) on the eastern Alpine margin, the same original slope of about 1 % (southward) can be assumed for our surface. Even if not horizontal as a primary surface, a tectonic tilting seems then likely to have affected the paleosurface.

RESIDUALS

The goodness of fit of regressions computed on residuals from trend surface is very low (32 %). No autocorrelation seem to exist therefore between deviations, neither systematic variations which could be geologically interpreted. Fig. 7 is a contour-line map of the deviations from the linear trend-surface. The area where deviations are higher is that of Margine di Momigno where the actual surface is over 100 m below the computed surface. This is also the largest of the upland surfaces, which could have been preserved because of a relatively lower uplift.

CONCLUSIONS

The uplift trend supports the Plio-Quaternary evolution model of the inner Apennine Chain whereby, due to crustal thinning, a block tectonic is set up. Except on the few areas covered by marine (mostly Pliocene) sediments, the uplift pattern of the blocks is mostly unknown. The present study is a first attempt of dealing with the problem, at least in the limited area where remnants of paleoforms can be observed. In the studied area the uplift appears to be characterized by two main components:

– a tilted, meridian directed regional uplift, well correlated with the geographic position of the studied area if compared to the Apennine main chain. This trend is « described » with good accuracy by the first order or linear trend-surface;

– block-like differential movements which led the southern lying summit areas to be less uplifted than the northern ones. Because of this second trend component, the 2° order surface adds 9.95 % to the total sum of squares.

The 2° order trend points to a higher « uplift gradient » in the eastern than in the western areas. This behaviour is completely different from that inferred for the nearby lying M. Albano Ridge which is a Quaternary tilted fault block with the master fault on the south-western side (BARTOLINI & PRANZINI, 1979; fig. 1). The different uplift pattern of the studied area and of the M. Albano Ridge, points to a Quaternary activity of the Livorno-Sillaro Line (BORTOLOTTI, 1966), which is in part the Livorno-Pistoia Line (BARTOLINI & *alii*, 1983), dividing the two structural highs (fig. 8).

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