ULTRACENTENNIAL PERIODICITY OF SOLAR ACTIVITY AND SOIL FORMATION*

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A comparison is made of the periodicity of change in the index of soil formation and solar activity over the last 5000 years. The index of soil formation — *(J),* the difference between the thicknesses of the humus horizon at certain points in time divided by the time separating these points — has been determined for 100-year intervals, it ranges from +1.55 to −2.00 mm/year and is the resultant between the growth rate of the humus horizon on soil formation and its decrease on denudation. It has been established that the maximal У values relate to the minima of solar activity and vice versa. The periods of its minima and high У values are favourable ecological conditions in the steppe zone. The findings may be used to evaluate the rhythms of the development of the biosphere.

The link between different phenomena in the biosphere and the periodicity of solar activity was demonstrated and studied by Chizhevskii, Eigenson and other investigators. Eddy [1] reconstructed the course of solar activity in the last 5000 years. In connection with the appearance of the unique factual data on the evolution of steppe soils the possibility has now appeared of looking at the relation between the rhythms of soil formation and the periodicity of solar activity.

The material on young, neoformed and buried soils obtained by the authors and the published findings made it possible to calculate the rates of change in the thickness of the humus horizon (A, + B,) of the black earths of southern and dark chestnut soils ***(in toto)*** chiefly for intervals of 100 years over the last 5000 years for the territory of the northern Black Sea coastal region in the southern Ukraine (the Odessa, Kherson, Nikolayev and Dnepropetrovsk regions). Over 1000 sections were studied in a territory of 200 monuments of antiquity of the Iron and Bronze Ages and the Eneolithic (settlements, barrows and mounds). We used 137 mostly archaeological datings of the soils. The dating errors amounted for the Iron Age, on average, to ± 25 years and for the Bronze epoch to ±50—100 years [2].

All the factual material used in this work may be divided into two groups: the first are soils formed on cultivated layers and dykes, the time of the origin of which is known from archaeological data. These are soils with a "floating" nul moment of soil formation belonging to the ninth century BC to the seventh century AD. The morphology of these neoformed soils in a series

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of wide sections were studied. The objects studied were located on water divides and inter-trabecular spaces, terraces and steeply inclined slopes (to 2°) in a range of absolute heights of 7—48 m. In all cases, for the best match to the conditions of the zonal soil formation process, the key parts of the soil investigations were chosen within plant associations with a floristic composition and projective cover close to root phytocenoses. The investigations covered the archaeological monuments of the main regions of the southern and dry steppe of the northern Black Sea coastal region Podunav (Orlovka, the lower Trayanov ramparts), Pridnestrov' (Nikonii, Nadlimansk I and the site of an ancient settlement, Roksolany VII), Koshary, Mys, Pobuzh'ya (Oliviya, Kozyrka XII, Katelino I, Chertovatoye I, IV, the burial site of the settlement Chertovatoye II, Shirokaya gorge I, Zakisova gorge I, Dmitrovka I, Kutsubur I, Beikush, etc.) and the Crimea (Kalos, Limen, Geraklii, Mysovye II, Semenovka I, Zenonov, Khersones).

The second group comprises soils buried beneath barrows in the time interval 5000—800 years ago. We used the data of Zolotun [3] on the Odessa and Nikolayev regions and in the Crimean Republic in the Ukraine and our material [4, 5] on the Dnepropetrovsk region and other published sources. The archaeological monuments are located on water divides and inclined slopes of losseal plains, that is, in similar geomorphological conditions, which made comparison easier [2].

Comparison of the records on the properties of the soils and the thicknesses of their humus horizons revealed differences in the absolute values because of the different duration of soil formation. However, as a rule, the age of the soils was over 1000 years and the humus horizon in a quasi-equilibrium state with the environment, and this allowed us to use the rate of change in the thickness of the humus horizon for one year as an indicator of soil formation.

The rate of change in the thickness of the humus horizon in time is one of the integral indicators of soil formation reflecting its intensity in relation to denudation. We call it the "soil formation index" and denote it as ***J***. Then $J = m^2 - m^x/t$~, — where /и,, m^2 are the thickness of the humus horizon at the points in time ?, and ***U***. A value of $J > 0$ denotes that the rate of increase in thickness of the humus horizon as a result of biological turnover of organic matter (entry into the soils of the litter of above and below ground plant organs and its humification), the penetration of the humus to a depth in solution, as a result of bioturbations, the derivatives of the soil mesofauna, and the filling in of cracks with humus material, exceeds the rate of denudation, i.e. the soils grow from top down. Other factors of increase in the thickness of the humus horizon are the deposition on the surface of mulched soil dust and also increase in its volume as a result of destructuring and increased porosity causing growth of the soils from bottom up [6].

The magnitude $J < 0$ signifies that the rate of denudation, erosion and deflation exceeds the rate of growth of the humus horizon through the magnitudes listed. At $J = 0$, the processes of soil formation and denudation are in balance.

Characteristic of water-erosion and deflation processes are activation and damping. Destruction of the soil profile is often determined by rarely repeated processes. For averaged calculations the extent of destruction is uniformly redistributed over the time intervals [7]. Much information is available on the values of averaged normal erosion. Thus, in the U.S.A. on slopes well fixed by vegetation (up to 35°) with annual rainfall from 500 to 1200 mm, the mean weighted value (307 year-experiments) of normal erosion was 0.5 tonnes/ha a year (0.05 mm/year) [18].

In the forest steppe of European Russia in the last 40 years the maximum values of the annual modulus of runoff of suspended deposits exceeded the minimum by a factor of 23-72 [9]. In the south-west of the east European plain the last 150 years have seen three rhythms of morpho-genesis [10], for the semi-arid regions the last 5000 years have witnessed four periods of activation of deflation; 1000-850 BC, the start of our era to AD 600, AD 1000-1200 and AD 1400 to the present [11].

To judge the processes of denudation in the territory of the region investigated, one may enlist the data of Shostakovich [12] on the thickness of the annual layers of silt in the Saks Lake (north Crimea in the town of Yevpatoriya) for 4200 years. These data were highly rated by researchers [13], used for reconstructions of the amount of atmospheric precipitation [11] and the multi-century variability of the Dneper runoff [7]. For centennial averaging, the mean annual thicknesses of the silt layers ranged from 1 to 2.5 mm/year, the periods of their changes show links with the variations in solar activity and changes in J. An inverse relation is noted between the thickness of the mean annual silt layers and J. For $J = -2$ (predominance of denudation over soil formation) the mean annual rate of accumulation of silt is close to 1.7 mm/year, for $J = 0$ (equilibrium between denudation and soil formation) it is 1.3 mm/year. Extrapolation of the linkage line beyond the region of factual data suggests that at $J = 4$ (intense soil formation, heavy turfing of the surface) denudation practically ceases and the thickness of the annual silt layer becomes vanishingly small. All this shows that negative J values are actually due to intensive denudation and analysis of the relationships of the rates of soil formation and denudation on specific drainage systems is a promising line of research.

Specific data on the course of change in J are given in Fig. 1c.

To clarify the relations between the index of soil formation and astroclimatic cycles, we used Eddy's scheme of reconstruction of the course of solar activity in the last 5000 years [1] (Fig. 1a, *b*). It is based on information on change in the content of ^{14}C in the annual rings of the trunks of relic pines and on unusual atmospheric phenomena contained in yearbooks and other historical writings.

Eddy noted that the "change on the Sun is a dominant factor of climatic changes lasting from 50 to several hundreds of years" [1, p. 329]. It has been established that, in years of maximum sunspots, about 2.5 times more droughts are observed than in years of diminished solar activity [14]. It is noted that destructive rarely repeated deluges are related to the years and periods most at risk from deflation. Judging from Eddy's scheme the duration of the maxima of solar activity (150—250 years) was adequate enough to be reflected in the morphology of the soil profile of the denudation trend of development of the soil cover (Table 1).

Correlation analysis of the dates of the extremes of solar activity (maxima and minima) with the corresponding dates of the extremes of the intensity of soil formation (minima and maxima) (Table 1) showed that between these events there exists a close tie (correlation coefficient $r \pm t_{0i}; S_r = 0.99 \pm 0.10$ (0.89—1.00)). A significant inverse relation exists between the minimum and maximum values of the indices of soil formation and solar activity (reciprocal coupling coefficient $K = 0.53$, $\chi^2 = 12.5$; $\chi^2_{01} = 9.5$; $\chi^2_{05} = 13.3$). Thus, the functioning of a natural dynamic "soil formation—processes of denudation" system has for the first time been shown to depend on ultracentennial astroclimatic cycles.

The chrono-interval lasting 1200 years between the Middle Age and Roman maxima was characterized by the raised voltage of the magnetic field [15], the greatest errors of the radiocarbon method and, consequently, uncertainties in Eddy's scheme. The determination of soil formation by solar rhythmics allows it to be used for the following correction of Eddy's scheme (Fig. 1 *a, b, c)*

Eddy's Middle Age maximum (750 years ago) had a shorter duration. The second middle age maximum predicted [16] for the seventh to ninth century interval is localized by us as the ninth century AD. This period is known for its climatic anomalies in the Black Sea coastal region, in

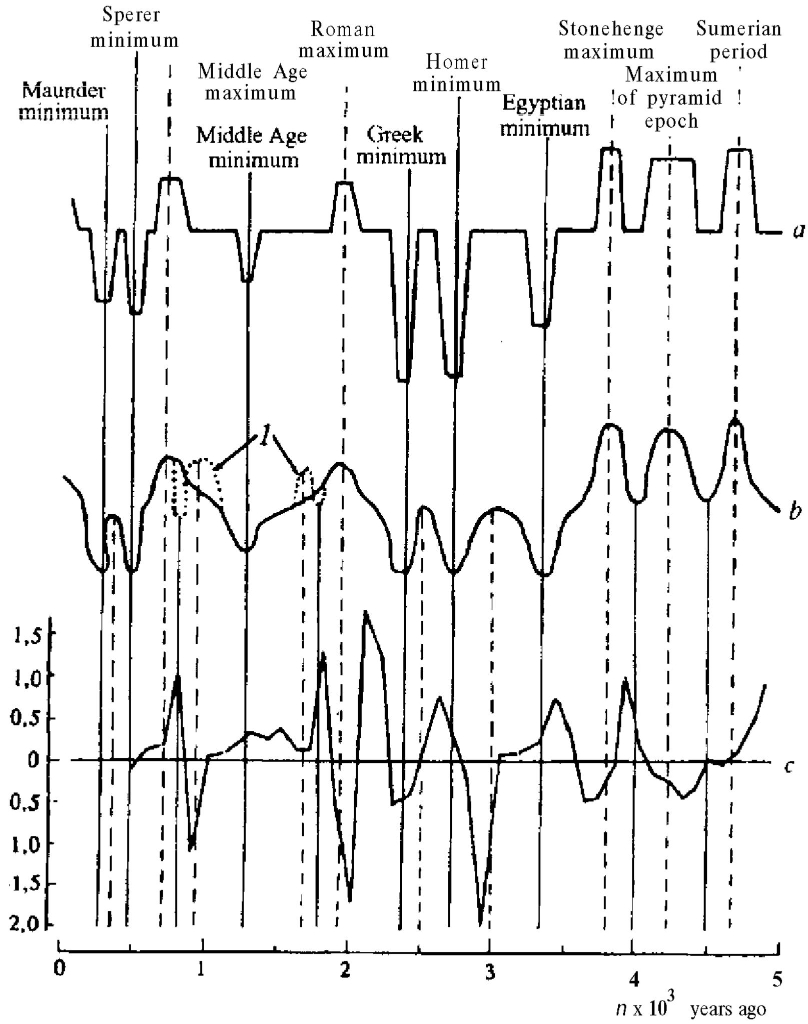

Fig. 1. Modern graph of the course of solar activity (after Eddy, 1978) and change in the soil formation index for the past 5000 years: *a,* solar activity (content of ^{14}C); *b* solar activity (envelope of number of sunspots): /, hypothetical changes in solar activity according to soil-evolutionary and other data; *c,* values of the soil formation index *(J),* mm/year. The maxima and minima of solar activity are denoted by vertical lines — broken and continuous, respectively.

particular, by the complete freezing of the Black Sea in 762 [17]. The Late Sarmatian maximum not noted by Eddy was related to the maximum of the magnetic field voltage [15] and to the period with low intensity of soil formation at the end of the third century AD. The two maxima were probably separated by the first middle age minimum of solar activity dated in the ninth century from the maximum value of the soil formation index.

Finally, the relative maximum of solar activity (Herodotus) took place in the fifth century BC (low intensity of soil formation; freezing of the Black Sea from Khersones to Pantikapeya, according to the evidence of Herodotus [17]).

Analysis of Fig. 1 and Table 1 shows the following.

1. The value of the soil formation index for the past 5000 years underwent periodic variations with a sweep from + 1.55 to - 2.00 mm/year with a step from 100 to 500 years.

2. The maxima of the values of the soil formation index (7 of 9) relate to the minima of solar activity. The minima of the soil formation index (6 of 7) relate to the maxima of solar activity.

Table 1. Periodicity of solar activity and change in the soil formation index *(J)* in the southern east European plain in the last 5000 years.

Solar activity, name, date (years ago)	Index *J*: date (years ago); value (± mm/year)		
	Maximum	Minimum	Mean level
Maxima	*n* - 0		*n* = 3
+(First) Middle Age, 750	-	-	**750, + 0,20**
(Late Sarmatian), 1700	-	-	**1700, + 0,20**
Roman, 1970	-	**2050, - 1,75**	-
Stonehenge, 3770	-	**3700, - 0,50**	-
Epochs of the pyramids, 4250	-	**4300, - 0,50**	-
Sumerian, 4720	-	-	**4650, - 0,05**
++(Second Middle Age), 1000	-	**950, - 1,15**	-
Herodotus, 2550	-	**2420. - 0,50**	-
Late Bronze, 2800-3200	-	**2950. - 2,50**	-
Minima	*n* - 7	*n* = 1	*n* = 2
+ Maunder. 300	-	-	-
Sperer, 500	-	-	**500, - 0,15**
(Second) Middle Age, 1300	**1350, + 0,25**	-	-
Greek. 2350	-	**2150, - 0,50**	-
Homer, 2720	**2650, + 0,80**	-	-
Egyptian, 3720	**3450, + 0,70**	-	-
++(First Middle Age), 850	**850, + 1,00**	-	-
(Late Sarmatian), 1800	**1800, + 1,30**	-	-
(Middle Bronze), 3920	**3950, + 1,00**	-	-
(Early Bronze), 4500	-	-	**4500, + 0,00**
(Late Atlant), 5000	**4900, + 1,00**	-	-
Mean level	*n* - 2	*n* - 0	*n* = 1
1100 - 1350	-	-	**1100 - 1350,**
			+0,10 - + 0,30
2200	**2200, + 1,55**	-	-
3500	**3500, + 0,50**	-	-

Note: N = 22; n = number of correlations.
\+ Maxima and minima — values above and below the mean level (for J: > and < 0.20; mean ± 0.20 mm/year).
++ Relative maxima and minima — values of mean level comprised between adjacent maxima or minima. Unbracketed names given by J. Eddy [!] and bracketed names by the authors.

Thus, an inverse ratio exists between the intensity of soil formation and solar activity. The periods of the minima of solar activity are epochs with favourable ecological conditions in the steppe zone.

3. The most significant deviation from this dependence is noted for the Greek minimum of solar activity (0 to —0.5 mm/year). No matches of the maximum values of the soil formation index with the solar activity maximum are noted.

4. The maximum differences in the thicknesses of the humus horizons of soils of adjacent time intervals do not exceed 5—10 cm.

5. The short time intervals in the course of which there were changes in the sign of the soil formation index from positive to negative may characterize epochs of ecological crises. The time intervals with change in the sign of the soil formation index from negative to positive and increased intensity of soil formation characterize improvement of the ecological conditions in the steppe zone.

6. Like the solar activity periodicity curve compiled by Eddy, the periodicity curve of the change in the soil formation index may be used for clarifying the rhythms of development of nature over the last 5000 years, for forecasting natural rhythms and for working out measures for the adaptation to them of human agricultural activity. The pattern disclosed further confirms the proposition that the soil is a mirror of the landscape and its history [18].

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