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Human Sociogeophysics – Phase II (Continued): Criticality in the Diffusion of Ethnicity Produces Civil Society

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Abstract: After a Phase I expansion at a constant population density, the earth's surface – the habitable niche of man – becomes filled. The subsequent global Malthusian constant (birth rate minus death rate) however remains unchanged. A criticality in density is thereupon reached, and a phase transition ensues. The most marked feature of Phase II is an onset of *condensations*, of settlements in place. The kinematics of Phase II involve (a) continued low growth rate of total population; (b) the continued diffusion of ethnicity with remixing; (c) fluctuating condensations involving local urban densifications; (d) local convective process fluxes (flows) carried on via trade and war rather than simple diffusive flow processes carried on via extensive local migrations; and (e) civilizational flow processes of convection governed by man-made rules for the diffusive transports of matter, energy, action and population.

The diffusion of ethnicity continues at an expanded space-time scale. The spatial scale is enlarged to the order of 300 km, with a corollary time scale of 1/2 to 1 millennium. This estimate is based on two physical notions: (a) a stability criterion for the transition, which provides an estimate for the number (density) of neighboring condensed population centers that need be involved in the trade-war convections (on the order of 16) and the range domain for these centers (on the order of 200–300 km); and (b) continuance of the diffusion of ethnicity as marked by a diffusivity relation ($d_1^2/t_1 = d_2^2/t_2$) where $d_1 = 50$–80 km (prior hunter-gatherer spatial scale), $t_1 = 30$ years (prior hunter-gatherer time scale), $d_2 = 300$ km (subsequent settlement spatial scale), so that t_2 (subsequent settlement temporal scale) approximates 500 to 1000 years.

While the total human ensemble represents a unitary "human" culture (in Braudel's term, a "world-economy"), it also contains a plurality of cultures in the anthropologist's sense, which now continuously diffuse and rediffuse, mix and remix. This continuing diffusion of ethnicity at the longer and larger scales produces longer and larger-scale fluctuations – fluid-like, transitory, large moving – which begin to constitute the politics and economics of civilizations. Trade and war become civilization's macroscopic flows, surplus production and states and empires its macroscopic patterns and forms.

Discussion

We have suggested (Iberall, Wilkinson 1984) that an initial "Phase I" expansion of man on earth (40,000–15,000 ybp) can be described and explained in terms of a physical model. Man *diffused* into the total available human geographic habitat (all land regions save the most severe arctic and desert wastes), at a constant density of about 0.04 persons per km^2, by a "random walk" process involving a diffusive velocity of about 1 roaming range (50 km) per generation, or 1,5 km per year, with little remixing.

Through an estimate of the time (about 15,000 ybp) at which the entire feasible habitat (about 100 million km^2) was occupied, and of the nominal birth and death rate

(0.03 per year), we were able to estimate the total earth population (Iberall; Wilkinson 1985). Furthermore we estimated the Malthusian constant, the net rate of increase of population (birth rate minus death rate) to be of the order of 0.0003 per year through both the Phase I expansion (from 15,000 ybp and continuing at least through 1,000–2,000 ybp). This second phase was characterized by population condensations (via horticulture) to civilization and agriculture. We pointed out that the condensation process was satisfactorily modeled by a continuation of Brownian random-walk diffusion, in a mixing model as provided by a confined and filled field/niche under the pressure of the same small positive Malthusian constant that originally filled the habitat. That positive Malthusian constant has been a measure of the social pressure driving man globally.[1)]

We shall next undertake a further examination of Phase II, with particular attention to the rescaling of human communities that accompanies their enlargement and densification in the settlement process, all of this of course occurring well before the very modern demographic 'transition'.

The Changed Scaling of Civil Society: Physical Model

It is clear that in some highly significant sense the areas of settled societies are larger and their cyclic fluctuations longer than those of hunter-gatherer bands. Can we find a physical basis for this new scaling?

Imagine the surface of a sphere tightly packed with circular cells 50–80 km in diameter: in particular the land habitat of the earth as part of such a surface. This is an idealization of the human ecumene toward the end of Phase I. The cells are the (volatile!) occupancy regions of hunter-gatherer bands. The more detailed specification of such cells depends largely on their relation to river-valleys and other sources of water. Diffusive motion among such hunter-gatherer communities is defined in terms of random-walk steps into or between regions. The expansive movement that resulted in this gas cell-like environment was a diffusion whose discrete steps were taken not much faster than a human generation. That movement, considered on a suitable time scale (25,000 years) and at a suitable observational interval, would if abstractly mapped and kinematically displayed have clearly shown the characteristics of an atomistic *flow field*.

Flow fields have been abundantly studied by physics. The most striking subject of such study is the *flow transition*. When the flow rate of a very smooth stream is sufficiently speeded up, it undergoes a transition to another flow pattern. The flow transition from one such pattern to another – and most notably from smooth flow to turbulence – is said to take place at a *criticality condition*.

When a field is overstressed, its state, whether solid or fluid, transforms. Euler's study of the buckling column is a classic originating example for such criticality theory. A thick column placed under pressure compresses; a thin one buckles. Why? As the ratio of length to diameter increases, a column under compressive load will reach some point at which it will buckle before it significantly compresses. The point at which it buckles is the criticality point; Euler's was the first transparent physical model of criticality (in elastic solid fields).

Reynolds in his 1870 study of flow fields showed that there was a criticality relationship between smooth laminar flow and a changed pattern of turbulent flow at increasing pressure. At some pressure, a laminar flow becomes turbulent, i.e. a new pattern emerges: a critical pressure creates pattern. This finding is of the same nature as Euler's. In the case of the buckling column, a lateral displacement appeared, supplementing the axial displacement; in the flow case a lateral eddying movement (pattern) appeared, supplementing the axial flow movement. It was Reynolds who showed that the speed of the flow is the determinant of the criticality condition, and thus of the transition from smoothness to turbulence. Hydrodynamics produced the theory for criticality in flow transitions, in the form of a criticality measure, the Reynolds number. Other criticality numbers are known. The Richardson number represents vertical instability in meteorology; there could be a Prigogine number for the criticality condition in chemical steps.

Our analysis of human sociogeophysical processes requires some small physical insight into the flow causes of criticality. There are two types of flow field processes. One is a dilatational flow field, the other a shear flow or drag flow field. The shear flow field's criticality transitions have been most studied. In a shear field, moving sheets and layers drag other sheets and layers with them by lateral momentum transfer. The dragging fluid is said to be viscous. The lateral eddying transitions due to differential drags have been extensively studied since Reynolds, whose work began more than a century ago. In dilatational fields, the stress, which creates a uniform hydrostatic pressure, in addition internalizes its motion by the creation of atomistic associations. (For this to occur, the fluid must be compressible and capable of developing internal complexity, i.e. its atomistic subcomponents must be capable of developing a cooperative complex via some attractive force.)

Recently, the stability criterion for flow fields has been generalized (Iberall, Soodak 1978) to cover both shear flow transitions and dilatational matter condensations (such as changes of phase from gas to liquid to solid). The criticality condition in general may be represented as the ratio of a convective velocity that sweeps into a field, to a diffusive velocity which can be supported by the already-present atomistic components of the field, thus:

$$R = \frac{V(\text{convective})}{V(\text{diffusive})}$$

Where V(convective) is the intruding convective velocity, and V(diffusive) is the diffusive velocity which the field can permit, their ratio R is the *generalized Reynolds number*.

Criticality occurs when that ratio (the generalized Reynolds number) reaches or exceeds unity: when the velocity of what sweeps convectively into a field is greater than the velocity of diffusive movement that the field's current atomistic contents can absorb.

When a flow field reaches criticality, *cooperative diffusivity of some sort supplants molecular diffusivity* as the means of absorbing energy. That is to say, in a more general sense, *structures or processes on a larger scale emerge*. For instance, in a flow field dominated by shearing forces, eddies are local patterns of "turbulence", local structures which absorb energy into their angular momentum. (Such process patterns can also be seen in so-called Bénard cells or in the large scale air mass movement in the atmosphere.) Such absorption of energy into a cooperative molecular movement is known in fluid mechanics as eddy diffusivity. Eddies may at one at the same time show a marked persistence in location and a highly energetic local behavior – an "identity" (form) and a "character" (function or process). *An energy overload in a flow field, producing stress, creates pattern.*

But the rule that pattern is created in a shear flow field when that field passes a criticality holds interest beyond the shear flow-field realm.[2] It also serves to describe matter condensation processes. Matter condensation is represented by the development of cooperativity or associativity, as for instance in a phase change, e.g. gas to liquid or to solid. Fields have more than one way of handling excess energetic entrance. If one labels eddies as we commonly visualize them "externalized" patterns of motion, it becomes possible to conceive of "internalized" patterns: the product of a rapid influx of momentum that cannot be handled by the diffusivities in a field may be the creation of new more or less permanent coalitions among the atomistic entities, if the energy to bind them can be carried off quickly enough.[3] Condensation phase changes are thus an alternative means of handling energy overloads on a flow field dilatationally stressed for "radial" inborne flow fields, as opposed to the "lateral" formation of momentum governed eddies. In the former case the matter/energy flow is "radial": matter is inborne toward a condensing center; the binding energy flow is outborne, carried away and otherwise shared. In the latter case, the matter/energy spins in place, as vorticity, in the form of "eddies" (Iberall, Soodak 1978; 1985).

The concepts of flow field, stability, criticality, cooperative diffusivity of eddies, and cooperative matter condensation, taken together, allow us to comprehend the process of dense human settlement in a new way. *The fact that the roaming hunter-gatherer settled and condensed has to suggest that in some way the diffusing flow field of hunter-gatherer bands, the packed earth's surface of late Phase I, passed a criticality threshold.*

The Changed Scaling of Civil Society: Energetic Aspects

In (Iberall, Soodak 1978) we physically demonstrated the criticality condition by appealing to a psychrometric process in which heat and mass transfer take place through the same boundary flow field. We applied our criteria to the hunter-gatherer transition. The psychrometric process (in which heat and mass transfer take place in the same flow field) is shown in the wet bulb thermometer used to measure the humidity by the cooling (wet bulb temperature depression) of a wetted thermometer. The process involves the ratio of heat flow inborne toward the bulb to mass flow (evaporation) outborne from the wetted surface, taking into account the heat of vaporization[4] of the condensed atomistic players. The psychrometric constant is heat flow/(mass flow × energy of evaporation). The process has three components: two flows, one phase change. Matter condensation is represented by the psychrometric process in reverse (e.g. as a dew point). Thus the psychrometric process provides the basis for a first theory of form because we account for a *phase change* (vapor to liquid, or even the more formal condensation in the narrow sense, e.g. of vapor to solid ice) in terms of the reciprocal exchange of energy and matter *flows*.

Physics begins with quasi-static images, and then tries, one step at a time, to fill out a picture of the dynamical processes. Bonds are made by extracting energy (and broken by putting energy in) – the heat of condensation, the heat of transformation. The obscure aspect of the psychrometric process is that the heat and mass transfer have to occur essentially instantaneously.[5] The mere presence of a condensing density fluctuation among a collection of atomistic players does not guarantee that a bonding (and phase change) will occur. The atomisms that bond are not those that come in with a velocity (their momentum measure) and leave with the same velocity, but those which ingather with a fast propagative velocity and leave with a slower diffusive velocity. The bonding process takes place relatively instantaneously, faster than diffusion, as fast as propagation. But this is an *implosion*, a coming together with the explosive velocity associated with propagation, a high-speed exchange of energy and mass, a giving up of bonding energy to form the bound of collective assemblage. The inborne imploding velocity is accompanied by an outborne release of the binding energy which is then carried away convectively.

In (Iberall, Soodak, 1985) we have made the derivation of a first theory of form more transparent, moving from the psychrometic version to showing form's implosion from fluid atomistic association to bound-state association to be a necessity, a criticality that has to emerge once an attractive force between atomisms is posited.

Do sedentary societies really differ in their energetics from their mobile precursors? It is clear that in many sig-

nificant senses this is exactly the case. A society of considerable population density, settled in place, has appreciably greater energy bound in what might be referred to as the "social contract".[6] You neither walk into nor away from a modern urban society by putting in 'just' the energetic cost of walking. There is a large amount of associational energy tied up. The process of sedentary production of goods, of holding on to the necessities of life, in condensed population centers, and the voluminous storage of such goods in, and trading between, centers (even with the post-barter counterflow of currency, value-in-trade tokens rather than goods) is a highly and increasingly energy-absorbing process.

Mobility exists in any field, but what moves changes with phase changes. What "moves" in the human social field changes with the human phase change from fluid movement to settlement. The hunter-gatherer band takes minimal food reserves, its few tools, and all its members with it. It displays large-fragment or whole-population mobility. Sedentary humanity convects a very much smaller proportion of its population (migrants, vagrants, refugees, travelers, traders, missionaries, diplomats, soldiers); it binds its members and stored goods to much more restricted locales. But it also convects an immensely larger quantity of goods (and counter-convects value tokens): this is the chief form of field mobility under conditions of human condensation-in-place.

A good historical atlas (e.g. Barraclough; Kinder and Hilgemann; McEvedy) will display, for unsettled humanity, arrows showing the flow of entire bands – Scythians, Hyksos, Sea Peoples, Sakas, Hsiung-nu. For settled humanity, such an atlas will show urban centers linked by trade routes and by military campaigns. *The life processes thus represented are strictly related*. One (trade/war) not merely displaces the other (band migration) but substitutes for it in a theoretical sense. It is the energetic process that is representative of the bound configurations of phase change into liquid or solid matter condensation systems. And such processes are in a certain sense obligatory while the condensation systems are stable. If you want to see the fluidity, the mobility of the gas state again, you must put in a great deal of energy to "boil" or "sublime" the condensed state. Mobile utopias and dystopias – Buckminster Fuller's "electronic nomads"; the post-apocalyptic "wanderers in the rubble" – both entail major energetic transitions, the former controlled, the latter catastrophically uncontrolled (nuclear explosions, natural catastrophes).

The Changed Scaling of Civil Society: Spatial Dimension

The appropriateness of our chosen physical model (flow field criticality leading to mass condensation) for comprehending this empirical human social process (settlement patterns post hunter-gatherer) can be examined in numerical terms of space and time scaling.

In (Iberall, Soodak 1978) we have shown that when an ensemble of mobile hunter-gatherer societies, constituting a flow field of diffusing cells 50–80 km across, are required to abstract an energy input sufficient to pass criticality and permit field condensations, these 50–80 km cells will bind within (coalesce to form) a region of about 300 km diameter (that size balances their individual atomistic – human – energetic capabilities) in which there will be a substantial number of condensation centers, 10 to 20; say 16 as a soft approximation (that number balances the condensed population).

Driven by this sort of association of human settlements, some form of polity will emerge. In addition to the vigorous activity, flow and turnover of ethnic groups, which will continue, there will be vigorous activity and turnover in polities, never again quite matching or reducing to the ethnic turnover. "Nation" and "state", the one associated with breeding pools and the other with condensation centers, will differentiate, definitively; their mutual relations will now begin to be of interest.

The Changed Scaling of Civil Society: Temporal Dimension

It is possible to deduce from physical principles not simply the spatial scaling (200–300 km diameter) and the number of condensation centers (10–20) to be expected in a post-critical condensed human society, but also the time-scaling of its fundamental processes. The diffusive scale of the hunter-gatherer society was 30 years, about a generation. What is the diffusion scale for the new field processes? We reason that it is of the order of 500 years. How so?

Space-time relationships are fundamental features of both diffusive and convective processes. Diffusion, by a fixed mechanism, is marked by d^2/t relationships (the mean squared distance expands proportional to time); convection is marked by d/t relationship. Convection is a velocity process in which the distance traveled is proportional to the time of traveling. Diffusion (in the absence of external driving gradients) is an outward random walk that effectively goes nowhere – the mean motion in diffusion is zero. It is the mean *square* motion which is proportional to time t. Convection is directional, undriven diffusion directionless or omnidirectional. Convection moves from one place to another along a flow line. Diffusion spreads through an area or volume. What is proportional to time in linear convection on a plane is distance traveled; what is proportional to time in plane diffusion is area occupied.

It follows, then, that if we know the area occupied *and* the time scale of the diffusive process in one phase of a flow field, and if we know the area occupied in a second

phase after a critical transition (e.g. to turbulence, to condensation), we can deduce the time scale of the diffusive process which exists at the new spatial scale.

$$d_1^2/t_1 = d_2^2/t_2, \text{ hence } t_2 = t_1 (d_2/d_1)^2$$

For hunter-gatherer humanity, $d_1 = 50$ to 80 km, and $t_1 = 30$ years. For settled humanity, $d_2 = 300$ km. Then $t_2 = (300/50)^2 \times 30 \cong 1000$ years is a plausible upper limit, and t_2 $(300/80)^2 \times 30 \cong 500$ years is a plausible lower limit. We ought then to search for and expect to find diffusive processes in settled society that approximate a halfto-full millennium scale. If it is feasible for human bands to be forced to precipitate, then their emergent diffusion processes should promptly scale up proportionally to their larger domain.

The same processes that drove diffusion by one roaming range per generation would then permit some characteristic modifications in the *condensation* patterning on the order of a half-to-full millennium. If our theory is sound, some significant fluctuation, rhythm or cycling in the polity or political system ought to exist on the semimillennial to millennial scale.

Confirmations and Significance of the Scalings

If a large remixing process occurs at a semimillennial-to-millennial scale, it certainly does *not* take place at a generational scale, in which the individual atomism (I; thou) is still distictly discernible. The fact that the large scale of remixing is no longer a one-generational process has perhaps misled the paleohistorian, who may have preferred to see a sharp 'Mesolithic' transition to introduce a Neolithic – post-Neolithic age of settlement, of urbanization and trade. As hunter-gatherers are simple band atomisms, so their appropriate largest scale of movement is a single generation.[7] When they join to form a mixing-pot solvent of many ethic groups they are no longer a gas-like ensemble, so one must rescale processes up to the next level, as is normal in physics. But the process in question is still a mixing, and a diffusion; the only problem is the appropriate new time (and space) scale for the process. The paleohistorians have tended to look for groups to make sharp well defined moves. They do not. Rather they bind, interpenetrate, pick up local characteristics, combine. There is a tendency to think of paleohistorical events and transitions as sharply defined; we propose, to the contrary, that it is quite normal for a human social process to take 1000–5000 years to complete a transition. "Where did the Etruscans come from?" is the wrong question. The right question is "What are the totality of interactions on the way to the emergence of the Etruscans (or Phoenicians; or Egyptians, Mesopotamians, Chinese, Hebrews, Chicanos)?"

Murdock's *Ethnographic Atlas* asserts the independence of cultures beyond separations of a few hundred miles and 1000 years. Thus the numbers for our diffusive scalings are in concord with these limits. In fact, one might say that we have produced the theory with which to 'derive' (at least the magnitude of) Murdock's experimentally ascertained culture measures. As another facet of the diffusion and turnover problem, at the other extreme of high frequency, there is accruing evidence that even local rural settlements were not immune to diffuse turnover at rapid time scales. For example, a recent book, Laslett's second edition of *The World We Have Lost*, indicates very large fluctuations in village populations per decade in England a number of centuries ago, contrary to much conventional wisdom.

What remains to be examined in the Phase II expansion of the human population is (a) the fuller identification of the convective energy input that overloads the hunter-gatherer flow field, (b) the empirical demonstration that 200–300 km diameters are the suitable spatial scaling for settlements, (c) accounting for the scaling up of the social processes from river-valley to multicontinental physical scales, (d) the empirical testing of the 500–1000 year scaling hypothesis against macropolitical and macroeconomic trend data, and (e) connection of that scaling and its physical basis to macropolitical, macrosocial and macrohistorical theory.

Footnotes

1) This model in itself implies that human condensation is associated with a density criterion, as we shall argue herein. In no way does that preclude the emergence, nor the importance, of those other processes that paleohistorians and paleocivilizationists have also cited, e.g. the emergence of more complex religious forms, the emergence of records to augment abstract symbolizing and externalize memory functions. Their relation to criticality remains to be defined: we surmise that they too emerge from an internal social pressure and the consequent density criticality.
2) An eddy is not a "permanent" form. It is a "temporary" flow pattern whose characteristic scaling may be briefer and smaller than that of the flow from which it emerges.
3) Atomistic entities become individually free in their movements when they absorb sufficient energy to break their energetic bonds. Conversely they bind into preferred associations when they give up a sufficient ("characteristic") energy to compel such binding, e.g. the heat of formation, or the energy of evaporation or sublimation. To form a condensed phase requires energy to escape relatively rapidly, faster than the entities themselves can escape.
4) Note that this heat of vaporization or disassociation is the same quantity (in the opposite direction) as the energy of formation or condensation of the associated players.
5) Other bondings are also relatively instantaneous. Two people meet, they "suddenly" throw their fortunes together, and start the transactions of business – or marriage.
6) Whether such a contract exists formally or only as an imaginary, internally expressed commitment, hardly matters for our purposes.

7) Even though they have a trans-missible oral memory that may be near-semimillennial. That very memory capability foreshadows the stronger emergence of a civilization-scaled process. This "foreshadowing" is physically analogous to the foreshadowing of the condensation of a nonideal gas to liquid by its attractive force, or the foreshadowing of crystal symmetries in a fully condensed solid by fluctuations in the liquid state from which it emerges.

References

Barraclough, G. (ed.): The Times Atlas of World History. Hammond, Inc., Maplewood, NJ 1979.

Iberall, A.; Soodak, H.: Physical basis for complex systems – Some propositions relating levels of organization. Collective Phenomena 3, 9 (1978)

Iberall, A.; Soodak, H.: A physics for complex systems. In: Yates, F. (ed.), Self-Organizing Systems: The Emergence of Order. Chapt. 30, Plenum Press, NY 1985 (in press).

Iberall, A.; Wilkinson, D.: Human Sociogeophysics: Explaining the Macroscopic Patterns of Man on Earth – Phase I. GeoJournal 8.2 (1984)

Iberall, A.; Wilkinson, D.: Human Sociogeophysics – Phase II: The Diffusion of Human Ethnicity by Remixing. GeoJournal 9.4 (1985)

Kinder, H.; Hilgemann, W.: The Anchor Atlas of World History, vol. 1. Anchor Books, Doubleday, Garden City NY 1974.

Laslett, P.: The World We Have Lost. Scribner's, NY 1984.

McEvedy, C.: The Penguin Atlas of Ancient History. Penguin Books, Ltd. Harmondsworth, Middlesex, England 1967.

Murdock, G.: Ethnographic Atlas. Univ. of Pittsburgh, Pittsburgh, PA 1967.