Beyond Newtonian thinking – towards a non-linear archaeology

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Applying Chaos Theory to Archaeology

Henrik Gerding & Dominic Ingemark

In this article the authors suggest that chaos theory can provide us with a new perspective on archaeology. Newtonian thinking is predominant in archaeology, as well as in the humanities in general. This results in the hegemony of analytic methods and a linear way of thinking on cause and effect. However, chaos theory has shown that behind many phenomena that may seem random lies order. Since these complex dynamic systems cannot be approached by linear methods we must turn to chaos theory and non-linear science. Chaos theory has major consequences for our view of determinism and predictability.

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Verily at the first Chaos came to be
Hesiod.
The Theogony, 116.

It is no exaggeration to state that chaos theory, or non-linear science, has created a revolution in the natural sciences, giving a deeper understanding of and insights into phenomena previously incomprehensible. The development of this new scientific branch may be regarded as a shift of paradigms in a Kuhnian sense (Kuhn 1970). Although originally sprung from the natural sciences, chaos theory has gained popularity in other disciplines such as the social sciences and the humanities as well as in medicine and economics. Within the humanities it is the historians that have shown the greatest interest in the possibilities of chaos theory.

In this article we present the idea that chaos theory can be applied to archaeology. Our intent is not to provide new theoretical models but to offer a new perspective on archaeological theory. Within chaos theory lies the foundation for alternative views on determinism, causality and predictability. We want to draw attention to the fact that there is now a new base available for getting beyond the Newtonian, linear thinking, which is predominant in archaeological interpretation.

AN INTRODUCTION TO CHAOS THEORY

In order to evaluate what chaos theory can contribute to history and archaeology it is important to give a short introduction to the main lines and development of the theory. (For further reading see Crutchfield *et al.* 1986; Gleick 1987; Prigogine & Stengers 1984; Stewart 1989.) Chaos theory is the most widespread name of this growing field of research. It was first conceived by James Yorke in the early 1970s (Pool 1989:26), but although the name rapidly won popularity,

it has been questioned, as it implies randomness and disorder. In fact it is rather the contrary, as the theory shows that behind what may seem random lies order. This inconsistency has often led to confusion in the ongoing debate. Alternative denominations used in current literature are "non-linear science" and "the study of complex dynamic systems". However, these cannot be regarded as synonyms, as they carry slightly different meanings. Non-linear science is a closely related and partly overlapping sub-discipline of mathematics, but as the mathematician Stanislaw Ulam once commented, "To characterise chaos theory as 'non-linear science' is like calling zoology the study of 'non-elephant animals'" (Gleick 1987:68).

Complex dynamic systems has become a commonly used synonym of chaotic systems. However, chaotic systems need not be complex, since quite simple dynamic systems can
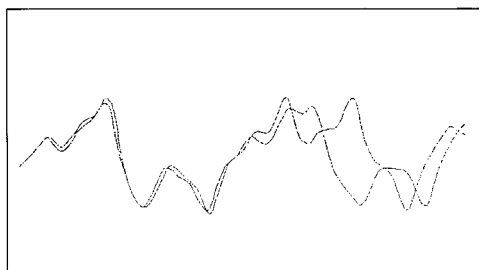

Fig. 1. Chaos was not made apparent until computers first arrived and computer simulations of non-linear systems could be made. When the meteorologist Edward Lorenz wanted to make a rerun of a weather simulation on his computer in 1961, he expected exactly the same result as in the first run. To save time, he typed in the initial value manually, using the numbers from an earlier printout. As he came back to look at the result he was shocked to find a completely different weather sequence. Lorenz had used a figure with three decimals whereas the computer memory worked with six decimals, causing an infinitely small, but crucial change in the initial value. (Ill. by Gerding after Lorenz 1963)

also generate a chaotic pattern. Edward Lorenz, a meteorologist, was the first to show this (Lorenz 1963, fig. 1). Taking into consideration the tradition already inherent in the concept of chaos theory, we will continue to use this name throughout the article.

Dynamic systems, that is systems in motion, can be said to consist of two different parts: parameters describing each successive state, and a set of rules that determines how the system evolves in time. The classical example of a dynamic system is the pendulum, the parameters of which are the angular deviation and velocity. One way of describing the rules governing the movement of the pendulum is by differential equations, the solutions to which give us the future development of the pendulum. Solving the differential equations, then, means that we can predict a future state of the system as well as retrodict a previous one. A dynamic system can also be described in geometric terms. State space (or phase space) is an abstract, multidimensional space where the parameters of the system are treated as co-ordinates. A particular state then becomes a point in the space. As the state varies in accordance with the development of the system, it traces out a trajectory, or orbit. State space is useful for visualising the behaviour of a dynamical system and reveals certain characteristics of it.

Another numerical representation of dynamic systems is by way of iteration, where a given "rule" is applied to an initial value (or values) producing a result that then takes the place of the initial value, going through the same procedure again. This transformation is repeated again and again but always with the same effective "rule". This sort of representation is suited for population growth, where the number of individuals every year can be calculated from that of the previous year, and so on. The same is applicable to all development in discrete time.

While studying non-linear population models by iteration, the biologist Robert May happened to come face to face with

chaos (May 1976). By constantly raising one parameter in a rather simple equation he found that the population, after first having converged towards a stable figure, suddenly began oscillating around two different convergence points. His continuing to raise the value of the parameter led to the creation of ever more equilibrium points, at an increasing rate, until the population each year seemed to fluctuate in a completely random way. The simple equation that "should" have produced a predictable pattern had generated chaos. The sudden shift, at a certain point, from a regular development into a situation where the future development can proceed along two different trajectories, is called a *bifurcation*.

One of the most important aspects of chaos theory is the principle of "sensitive dependence on initial conditions" or "extreme sensitivity to initial conditions". An infinitely small change in an input variable results in an unproportionally large change in the outcome if the system is chaotic. In a linear system, however, two starting points that are located close to each other will have similar trajectories, and the smaller the differences get, the closer the results will be. From this follows that linear systems are not particularly sensitive to measurement errors, whereas in chaotic systems an incorrect measurement will lead to a totally different result. As seen in the case of the population model, sensitive dependence is not constrained to initial conditions but can also appear in system parameters.

The ever present uncertainty in initial measurements, implied by quantum mechanics (Heisenberg 1993 [1971]:105), together with discontinuity and exponential divergence within non-linear functions is the reason why one can neither predict nor retrodict a chaotic system. In other words, *a chaotic system is unpredictable although it is deterministic*. By deterministic is meant that there is no randomness (in a stochastic sense) involved. The outcome is the result of a set of relations completely governed by the laws of nature. Still, the chaotic systems are unpredictable in all, or some parts, of their development. Another characteristic is that while a linear system can be broken up and studied in its parts without any information being lost, this does not apply to non-linear ones, which have to be studied in their entirety (Langton 1993:39).

One way of doing this is by observing the system in state space. Here the long-term behaviour of a dynamic system can be recognised as a geometric form, an *attractor*. An attractor is the behaviour that the system settles down to after some transients. The pendulum (in friction), regardless of initial position and velocity, will eventually reach a fixed state as it comes to a halt. Its attractor, therefore, is represented by a fix point in state space. For an ideal frictionless pendulum that continues in an endless periodic motion, the attractor is a closed curve. The attractors of chaotic systems, however, are quite different and have thus been termed "strange" attractors. They are basically a fixed subset of state space that is entered but never left again. The trajectory in the attractor is never repeated but can come infinitely close to a previous state (fig. 2).

An example of chaos in everyday life can be as simple as a dripping faucet. Although the drops of water sometimes seem to fall in a completely random way, the intervals forming a never repeating pattern, this supposed randomness is generated by a chaotic function without any element of chance. Furthermore, the strange attractor behind this chaotic pattern can be identified and analysed (Crutchfield *et al.* 1986:47).

THE DISCOVERY OF CHAOS
After leaving the basics of chaos theory we will now make a brief recapitulation of how it has evolved up to present time. Until our century the natural sciences had been based on linear mathematics. After the publication of Isaac Newton's *Principia* (1972 [1687])

there was an increasing belief in the possibilities of describing the world in mathematical terms, as well as predicting its behaviour. This deterministic view was brought to its utmost extreme in the ideas of the 18th-century mathematician Pierre Simon Laplace:

"The present state of the system of nature is evidently a consequence of what it was in the preceding moment, and if we conceive of an intelligence which at a given instant comprehends all the relations of the entities of this universe, it could state the respective positions, motions, and general affects of all these entities at any time in the past or future." (Laplace [1776], in Crutchfield *et al.* 1986:40)

Laplace's ideas had a major influence on science for over a century before they were seriously challenged. The first person to realise the importance of sensitivity to initial conditions was James Clerk Maxwell, who published his ideas in *Matter and Motion* in 1877. Yorke has also named Maxwell as the original discoverer of chaos (Hunt & Yorke 1993:3).

"... but there are other cases in which a small initial variation may produce a very great change in the final state of a system, as when the displacement of the 'points' causes a railway train to run into another instead of keeping its proper course." (Maxwell 1908 [1877]:21)

Since the beginning of the 20th century there has been a growing realisation that systems are not always linear. A French mathematician, Henri Poincaré, expressed similar thoughts as Maxwell in 1903, but carried them one step further:

"... il peut arriver que de petites différences dans les conditions initiales en engendrent de très grandes dans les phénomène finaux; une petite erreur sur les premières produirait une erreur énorme sur les derniers. La prédiction devient impossible et nous avons le phénomène fortuit." (Poincaré 1920 [1903]:68)

(... it may happen that small differences in the initial conditions produce very great ones in the final phenomena. A small error in the former will produce an enormous error in the latter. Prediction becomes impossible, and we have [a] fortuitous phenomenon.)

In 1963 the American meteorologist Edward Lorenz wrote the article *"Deterministic Nonperiodic Flow"* (Lorenz 1963), which can be said to be the corner-stone of chaos theory. This was followed by other equally important works, such as *"Predictability: Does the Flap of a Butterfly's Wings in Brazil Set Off a Tornado in Texas?"* (Lorenz 1979). This often cited title is perhaps somewhat spec-
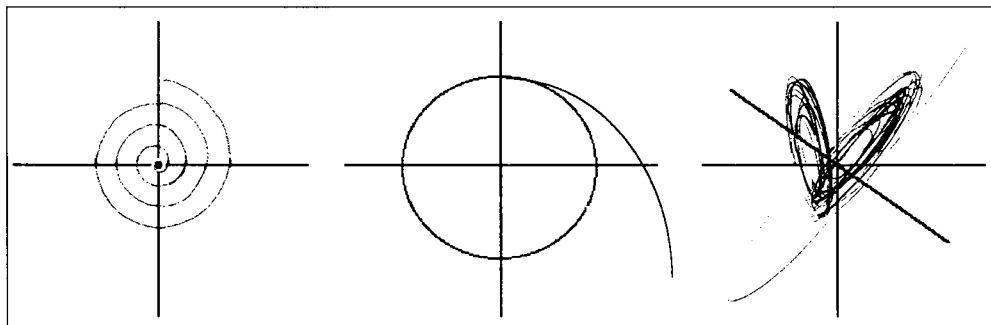
Fig. 2. An attractor can be regarded as the long-term behaviour of a dynamic system in state space, but also as a determinant of the system, that attracts the trajectories of different initial conditions and controls their future development. The two simplest kinds of attractors are the fixed point (left) and the closed curve, or limit cycle (middle). Strange attractors (i.e. chaotic attractors) have a much more complicated structure and correspond to unpredictable motion (right). (Ill. by Gerding after Ruelle 1994)

tacular but illustrates the principle of extreme sensitivity to initial conditions. The important thing is *not* that chaotic behaviour always results in drastic phenomena, but that as insignificant a factor as a butterfly's wings *can* sometimes make all the difference. Lorenz's ideas appealed to physicists and mathematicians and from these disciplines they have rapidly spread to other areas. Today chaos theory is used in biology, astronomy, architecture, economy, medicine and meteorology to mention a few disciplines. The reason for this is the growing realisation that linear phenomena are but small islets in a vast ocean of non-linearity.

CHAOS IN HISTORY AND ARCHAEOLOGY

As early as in 1984 Ilya Prigogine and Isabelle Stengers suggested that chaos theory could contribute not only to the natural sciences but also to the social sciences and the humanities (Prigogine & Stengers 1984). This idea was first adopted in philosophy (Hunt 1987; Stone 1989) and later in literary history (Hayles 1989) and theology (Steenburg 1991). In 1990 Charles Dyke wrote *"Strange Attraction, Curious Liaison: Clio Meets Chaos"*, in which chaos theory was first applied to the field of history (Dyke 1990). Although the relevance of chaos theory to archaeology was fleetingly discussed by Jes Wienberg and Stig Welinder in 1989/90 (Wienberg 1989a; 1989b; Welinder 1989; Welinder & Wienberg 1990), to our knowledge this topic has not been thoroughly investigated yet. However, Colin Renfrew did make use of the so-called catastrophe theory, one of the predecessors of chaos theory, already in 1978 (Renfrew 1978).

Many archaeologists are likely to question the introduction of chaos theory in archaeology. What relevance does newly won knowledge in theoretical physics and advanced mathematics have to the humanities? The distance between the natural sciences on the one hand and the humanities on the other

is not as great as one is often led to believe. Contrary to what many people believe, archaeology as well as history has been heavily influenced by the natural sciences, in particular Newtonian mechanics (Renfrew 1978: 203). "Durante más doscientos años la mecánica de Newton había cumplido una función de modelo para todas las teorías científicas" (Kanitschneider 1994:91, "For more than two hundred years the mechanics of Newton has worked as a model for all scientific theories").

It is our firm belief that these relations with the natural sciences are not only important to preserve but also to strengthen. As already mentioned, the natural sciences have mainly been preoccupied with the study of linear phenomena, until the last few decades. This was for want of ways to deal with the non-linear ones. Whereas the natural sciences have turned more and more towards non-linear explanations, the linear, Newtonian, thinking is totally predominant within the humanities. "The linear, billiard-ball conception of 'causation' has to be re-examined, and its hegemony as explanatory pattern of choice reassessed" (Dyke 1990:377).

Our purpose in trying to introduce chaos theory to archaeology is not to accomplish a shift in paradigms in a Kuhnian sense. Instead we strive to provide new perspectives on the current ones. The introduction of chaos to the field of history has turned out to be fruitful, although it has been far from the revolution that many hoped for. As we view archaeology as the study of long-term history, in the same sense as Ian Hodder (1987), the transition of the theory from history to archaeology is not very far.

To begin with it is our intention to discuss the consequences of this theory for archaeology as a whole, then to the different leading paradigms. The paradigms we have chosen to discuss are processual archaeology, postprocessual archaeology, Marxist archaeology and the Annales school. The latter, originally having developed within history, has had an

increasing influence on archaeology.

THE CONSEQUENSCES OF CHAOS THEORY FOR ARCHAEOLOGY IN GENERAL

One of the most important aspects of archaeology is the study of change, in particular changes in society. For this reason the question of *cause and effect* is crucial to our subject. Due to the linear way of thinking the standing point has always been that major changes, reflected in the archaeological material, must have major causes. Through the history of archaeological research there has been an ongoing debate on the reason for changes (Trigger 1993). Currently, there are three general groups of explanatory models. These are *centre-periphery* and *world-system*, which seek external factors (Champion 1989; Wallerstein 1974; Frankenstein & Rowlands 1978); *neo-evolutionary* models, which stress the internal factors (Binford 1983b: 377); and *peer polity interaction*, a reaction to the other two (Renfrew & Cherry 1986).

The tendency to attribute major causes to major changes is what the historian Donald McCloskey has called "the dogma of Large-Large" (McCloskey 1991:32). However, chaos research has shown that minor events and changes can result in major consequences (Dyke 1990:382). It is important, though, to underline that major changes also may have major causes. Chaos theory has, in other words, shown the importance of the single event and historical/archaeological detail, or as McCloskey has put it: "... in the end it comes down to Cleopatra's nose: If she had had a different nose, unattractive to Roman generals, the battle of Actium might not have happened,..." (McCloskey 1991:36).

This brings us to one of the most important aspects of chaos theory, i.e. sensitive dependence on initial conditions. The phenomenon is popularly called "the butterfly effect". As mentioned above, an infinitely small alteration of the initial conditions may cause an entirely different outcome, in a chaotic system. According to Michael Shermer,
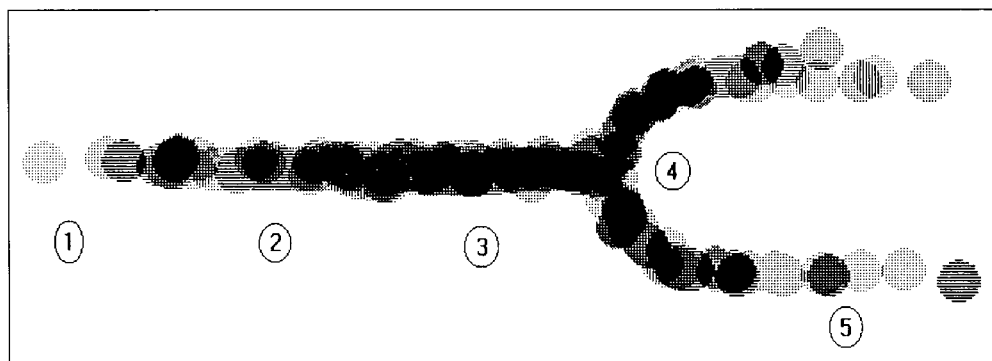
Fig. 3. Shermer's chaotic model of historical sequences is based on the concept of "contingent-necessity", visible in a number of well-defined intervals. At the beginning of a sequence the development is subject to contingencies and therefore both chaotic and unpredictable (1). As the cumulative power of actions and events builds up, the sequence is forced along a trajectory, increasingly run by necessity (2). The constraining circumstances gradually reach a level where minor influences no longer can change the direction of the path (3). Only if the well-established necessity is challenged by other, conflicting necessities, can a contingency push the historical sequence one way or another. This is a bifurcation point (4). When the old necessity is broken down, the sequence enters another phase of contingencies and starts anew (5) (Shermer 1995). (Ill. by Gerding after Shermer 1993)

however, it is only at certain points that a single event can bring about radical changes. He has identified these instances as bifurcation points (Shermer 1995:72, fig. 3). As Dyke also has stated, it is "under conditions of extreme *instability*", that a single event or an individual can totally alter the course of history (Dyke 1990:383). In periods of stability or during historical processes that have gained momentum, these single events have no relevant effect:

"The flap of the butterfly's wings in Brazil may indeed set off a tornado in Texas, but only when the system has started anew or is precariously hanging in the balance. Once the storm is well under way, the flap of a billion butterfly wings would not alter the outcome for the tornado-leery Texans." (Shermer 1995: 73)

Whereas George Reisch claims that history is characterised by constant instability (Reisch 1995:55), M. Shermer has developed the idea of bifurcations in history, and given it the following definition:

"... *any stimulus that causes a shift from the dominance of necessity and order to the dominance of contingency and chaos in a historical sequence. ... any point in a historical sequence where previously well established necessities have been challenged by others so that a trigger of change (contingency) may push the sequence one direction or the other.*" (Shermer 1993:7, original emphasis)

In other words a bifurcation point is a state where the historical development can take *totally* different directions, depending on only minor alterations of the conditions. One consequence of this is that two, originally very similar societies can at a certain point develop in two completely different ways. This has implications on all levels in society. On a lower level, in material culture, two different processes can give a similar result, as shown by Ian Hodder and Clive Orton (1976:8). Chaos theory now supports that two *almost identical* processes can give

different material results.

Predictability and determinism were previously seen as having been interlocked by necessity. However, with the coming of chaos theory this view has been overthrown. As already stated, a chaotic system is deterministic and unpredictable at the same time, due to the laws of quantum mechanics and exponential divergence. This has led Dyke to draw the conclusion that chaos theory has some practical implications on covering laws: "In practice, this means that outside of experiments, covering law explanations will work only for linear systems" (Dyke 1990:379).

Another consequence of the predominance of linear thinking is a tendency among researchers to reject data that do not fit in with the general pattern. This means that chaotic phenomena have always been mistaken for erroneous anomalies due to insufficient evidence and faulty data. This was particularly the case in the natural sciences but should be expected also in other fields such as the social sciences and the humanities.

"What they did not look for they did not find. Chaotic phenomena and nonlinear activity were literally and figuratively seen as anomalous data, natural noise, and experimental error to be dismissed." (Shermer 1995:62)

As already mentioned, Renfrew tried to apply catastrophe theory, created by the mathematician René Thom in the 1960s (Thom 1989 [1972]), to archaeology in the late 1970s (Renfrew 1978). As the name implies, catastrophe theory deals with sudden changes, for example the fall of the Mycenaean civilisation, due to non-linear behaviour. The discontinuity of certain non-linear functions can give rise to abrupt changes, although the development of the generating parameters are smooth and regular. In other words, sudden changes need not have sudden causes. Renfrew used catastrophe theory to explain changes in settlement patterns: shifts between extreme dispersal and nucleation into towns (Poston & Stewart 1978:412). The

sudden alterations shown in the archaeological record, thus, can be seen rather as the result of internal dynamics than evidence for invasion by a new "people".

PROCESSUAL ARCHAEOLOGY AND CHAOS THEORY

The most distinct feature of processual archaeology, or New Archaeology, is that it is nomothetic, that is law generating. The creation of general, or covering, laws which explain and describe societal and cultural change, is seen as the prime goal of archaeology (Trigger 1978:4-7; Binford 1989:16-17). Although this paradigm, and in particular its foremost advocate Lewis R. Binford (1983a:20, 1983b:42), is explicitly anti-historic, it has much in common with Carl Hempel's views on history (Hempel 1959). Hempelian history, as well as processual archaeology, create these laws on the basis of the natural sciences.

Among the leading paradigms in archaeology today, processual archaeology can be said to be the most linear. The hypothetic-deductive method is employed as a means of treating the archaeological record (Binford 1962). This method implies the possibility to make retrodictions, and therefore to predict history. Advances within the field of non-linear science, however, have shown that predictions are almost impossible to make, unless you know all factors with infinite precision. To reach this kind of precision is both practically and theoretically impossible, the latter due to Heisenberg's Principle of Uncertainty. The New Archaeology provided a new set of tools to interpret the past, and strengthened the links to the natural sciences (Clarke 1968, 1973). On the other hand it often excluded the individual human and the singular event. "The aim is not to reach the individual behind the artefact, but the system behind both Indian and artefact" (Flannery 1967). As mentioned earlier, these factors could be crucial to a chaotic system. "For processual archaeologists, sudden change,

discontinuous change, remains a problem" (Renfrew 1978:203).

It is important to underline that the processualists have made a major contribution in recognising the importance of the internal dynamics within societies. This was a reaction to the normative archaeology, which concentrates on the external factors in the explanation of change. Despite the dominance of linearity, non-linear systems are treated in New Archaeology even if they are not recognised as such. David Clarke, for example, speaks of "unstable equilibrium" and "metastable equilibrium", which apparently are non-linear systems (Clarke 1968: 49).

As an example of a typical processualist study one might look at the work of Tom Pilgram (1987). He has constructed a log-linear model for describing and predicting site densities from environmental factors. It is what could be called linear, descriptive analysis and has no explanatory value at all, as he himself has recognised: "... the model made little contribution to intuitive understanding of settlement process" (Pilgram 1987:v).

The main fault in this kind of linear model is that it does not take the interactions between different factors into consideration. These could be crucial for the outcome of the process as they have the potential to generate a chaotic system.

POST-PROCESSUAL ARCHAEOLOGY AND CHAOS THEORY

Post-processual archaeology is a post-modernist reaction to the modernist processual/New Archaeology and its stress on scientific rigour and objectivity (Kohl 1993:13). The post-processual archaeology can be seen as a return to humanistic values, and a move away from the natural scientific approach to the past. In practice, it parts from the extreme linearity of the New Archaeology. However, it has not parted from the use of natural scientific methods. Whereas proces-

sual archaeology, in many cases, can be considered as ahistorical, the post-processualists emphasise the traditional links between archaeology and history.

Post-processual archaeology has put the hypothetic-deductive method of processual archaeology in question (Hodder 1982:19-21), and rejected covering laws (Hodder 1986:25). This has resulted in an attempt to replace the quantitative analysis with a qualitative, more intuitive interpretation of the archaeological material (Kohl 1993:14; Myhre 1991:167; Wylie 1993:22-26). The exclusion of the individual in processual archaeology has been much debated within post-processual archaeology (Hodder 1985: 7; Shanks & Tilley 1987:61). Post-processual archaeologists hold an entirely different view on the individual human being, regarding him as an active participant in the social processes (Moore 1994:49). "... people are seen as active. They actively negotiate social rules, creating and transforming the social structure that is constructed by the individual" (Hodder 1985:2).

Post-processual archaeology applies synthetic methods in its study of the archaeological record, which is opposite to the analytic formulas used by the processualists. The former finds support in chaos theory, as there are reasons to believe that most historical processes are non-linear. An example of the post-processual, synthetic view is the rejection of the division of cultures into subsystems, as well as the division of history into phases: "In history there is only a stream of continuous events, no absolute hiatus, so the only explanation of change is a full account of change" (Hodder 1986:143-44). Although post-processual archaeology has not adopted chaos theory it puts greater emphasis on the single event.

MARXIST ARCHAEOLOGY AND CHAOS THEORY

Marxist archaeology comprises several elements which are closely related to chaos

theory, although there are others that stand in opposition to it. Karl Marx held the view that every society carries within itself the seed to the next, in a continuous sequence. And he looked upon the development from a primitive socialistic society, through slave, feudal and capitalistic societies as a historical necessity. Marx's view on the role of the individual is clear in *The Eighteenth Brumaire of Louis Bonaparte*.

"Die Menschen machen ihre eigene Geschichte, aber sie machen sie nicht aus freien Stücken, nicht unter selbstgewählten Umständen, sondern unter unmittelbar vorgefundenen, gegebenen und überlieferten Umständen." (Marx 1885:7)

(Men make their own history, but they do not make it just as they please; they do not make it under circumstances chosen by themselves, but under given circumstances directly encountered and inherited from the past.)

This view is extreme in its determinism and linearity, but can still be true in one sense. Chaos theory has shown that all non-linear processes, including historical, are deterministic, although they are not predictable. On the other hand the importance of the event, and therefore the individual, is made clear by chaos theory.

Marxist archaeology and dialectics are striving for a holistic view of the world and react strongly to atomistic tendencies (Bulkin *et al.* 1982:286; Childe 1951:31-34) predominant in, for example, processual archaeology (McGuire 1992:119-20). The methods required in the study of chaotic phenomena (i.e. synthetic instead of analytic) harmonise with this holistic approach. However, this aim has often led Marxist archaeologists to de-emphasise the importance of the individual.

"History is not, however, the sum of the individual acts; it is the product of masses of people whose action as social groups stemmed from common consciousness derived from the shared relations, experiences, cul-

tures, and ideologies that linked them to each other and to the world around them." (McGuire 1992:143)

In *A Marxist Archaeology* Randall Mc-Guire presents his view on history (McGuire 1992:171). History is seen as deterministic in the sense that all actions are constrained by prior conditions, but he only admits deter-minism to a certain point. Within the frame-work given by prior conditions he allows for a number of possible choices, subject to contingency. In this way the historical pro-cess is both constrained and unpredictable. McGuire speaks of every point in time as being a crossroads from which several paths can be followed. And by choosing one of these, all the others are ruled out. Although McGuire's standpoint is that history is de-terministic and unpredictable at the same time, the reason for this contingency is left unexplained. By using chaotic systems as an analogy, McGuire's view of history can be made more theoretically solid. McGuire's "cross-roads" can be equated with Shermer's "bifurcation points". The possibility, in his-tory, of taking different paths springs from the sensitivity to initial conditions. Even though McGuire does not refer to chaos theory, he has pointed to the fact that small events cumulatively can cause major effects on the course of history.

THE ANNALES SCHOOL AND CHAOS THEORY

The Annales school was originally a move-ment within French historic research (Burke 1992:21), which has increasingly influenced archaeology during the last decade (Bintliff 1991). One important trait of this movement is the rejection of the mere writing of politi-cal history and the ambition to replace this with a fuller view of society - *histoire totale*. In order to accomplish this it turned to other disciplines, in particular the social sciences and economy.

Another trait of the Annales school is its time perspective, where the historical proc-esses are divided into three categories (Bint-liff 1991:6): the history of events - *histoire événementielle* - or short term history; *con-juncture*, or medium term history, that is pro-cesses which reach over several generations; *la longue durée*, or long term history. The latter is defined by Fernand Braudel as the geohistorical circumstances that provide both limitations and possibilities of the develop-ment at all levels (Braudel 1972 [1949]:23-24). The view of the Annales school on time has much in common with Karl Marx as well as Max Weber (1978 [1934]).

The events are considered to be interes-ting only in the sense that they illuminate historical periods, but they are not seen as having any impact on the historical develop-ment. The history of events is merely seen as a "brilliant surface" (Braudel 1973 [1949]: 1243). In *The Mediterranean and the Medi-terranean World in the Age of Philip II* Brau-del states:

"Events are the ephemera of history; they pass across its stage like fireflies, hardly glimpsed before they settle back into darkness and as often as not into oblivion. Every event, however brief, has to be sure a contribution to make, lights up some dark corner or even some wide vista of history." (Braudel 1973 (1949):901)

Not only the single event but also the individual is given a minor and unimportant role:

"So when I think of the individual, I am always inclined to see him imprisoned with-in a destiny in which he himself has little hand, fixed in a landscape in which the in-finite perspectives of the long term stretch into the distance both behind him and before. In historical analysis as I see it, rightly or wrongly, the long run always wins in the end." (Braudel 1973 [1949]:1244)

The view of the Annales historians on the single event has been much criticised by the "Chaos historians", such as Dyke and Reisch (Dyke 1990:385-390; Reisch 1991:8-9). Dyke is of the opinion that the Annales school dis-

plays a linear view on history: "...[it] is a history that betrays its Newtonian roots. Or to put it more carefully, it is a history that betrays its Humean or Platonic roots, ..." (Dyke 1990:386-87).

However, we agree with Dyke (1990) in that the Annales school, apart from these objections, has many merits, and it is in particular the long-term perspective that relates to archaeology (Sherratt 1993:128; Hodder 1987).

CONCLUSION AND SUMMARY

The practical use of chaos theory in archaeology as a methodological tool is limited, *inter alia* because of the lack of complete and precise data but also due to the difficulty in identifying/defining significant "processes" or "systems", taking into consideration all the relevant parameters. However, chaos theory may still have a profound effect on how we construct models in the future and help us reach new insights. "In some cases interesting qualitative conlusions are possible even in the absence of a quantitative model" (Ruelle 1994:29). Two areas that are receiving much attention within chaos research today have the potential of providing us with a wide range of applications in a near future. These are strange attractors, mentioned above, and feed-back control of chaotic systems. As yet another way of dealing with non-linear phenomena, one might suggest neural networks.

We have now reached a point where we can structure our views into three general statements:

There have always been close ties between the social sciences and the humanities, on the one hand , and the natural sciences, on the other. In both cases the Newtonian, linear, thinking has dominated since the 18th century and the Enlightenment (fig. 4). However, during the 20th century there have been three major scientific revolutions within physics, taking it beyond the Newtonian framework. These are relativity theory,

quantum mechanics and chaos theory. We believe there are strong reasons to look at this development within physics and reconsider our own position. The best way of gaining new insights into archaeology, as well as into other scientific disciplines, lies in interdisciplinary contacts.

As we see it, the "mathematical" way of thinking no longer stands in opposition to the study of the contingent and disordered, as chaos theory now has provided us with a means of explaining the non-linear and discontinuous. One implication of chaos theory is that complex, non-linear systems can not be broken up into simpler constituent parts and studied in an analytical way, as in the

Fig. 4. Sir Isaac Newton (1643-1727). As the Newtonian physics made its triumphal entrance in one discipline after the other, the qualitative explanations of Descartes and others were relegated to the domain of curious speculations (Thom 1989 [1972]:5). A linear way of thinking was made pre-eminent. (Ill. from Newton 1972 [1687]:7)

case of linear systems. This explains why the processual/New Archaeology, in spite of thorough work and inventive ideas, in many cases failed to produce the expected results. As an alternative to analytical methods (which are useful for describing, calculating and predicting linear systems), we plead for a return to a more synthetic, intuitive app-roach in the interpretation of the archaeo-logical material (fig. 5).

Although these ideas may seem new, sev-eral of the points made have in fact already been on the agenda. Chaos theory now sup-plies us with a theoretical base for them. Many archaeologists would probably not agree with our regarding history and arch-aeology in terms of systems and processes, but there is still reason for using chaos as an analogy. Thereby it could help us to reach a deeper understanding of the internal dy-namics of certain phenomena. It is impor-tant to underline that we do not deny the existence of linear phenomena and pro-cesses. However, there are numerous indica-tions of non-linear ones being the most com-mon. They have been found *en masse* in the study of nature. We are surrounded by chaos as well as being part of it: "People call chaos a new phenomenon, but it has always been around. There's nothing new about it - only people did not notice it" (Ueda 1992:5).

The major consequences of the applica-tion of chaos theory to archaeology can be summed up as following:

– We need to re-evaluate the Newtonian, linear way of thinking on cause and effect, the so called "dogma of Large-Large". In chaotic systems major changes need not have large causes.

– The present view in archaeology, that equates determinism with predictability and vice versa, can now be rejected once and for all. A chaotic system is deterministic and unpredictable at the same time.

– The key feature of linear systems is that their constituent parts can be studied sepa-rately. This, however, does not apply to non-linear systems, the behaviour of which is dependent on the interactions between differ-ent parts. We must therefore strive for a ho-listic view, which primarily can be reached by synthetic, that is heuristic and intuitive methods.

If we thus conclude that the majority of the phenomena in history and archaeology are chaotic and non-linear, the question arises of how we are to deal with them. It may be suggested that one line of approach is to apply Edward de Bono's ideas about lateral thinking (de Bono 1986 [1970]) when inter-preting historical and archaeological prob-lems.

Lateral thinking can be said to be the opposite of vertical (logical) thinking. How-ever, it is not proposed that it in any way should replace vertical thinking, but rather work as a complement, as a means of making vertical thinking more efficient. *In our view the Newtonian, linear thinking is a character-istic example of what de Bono has termed vertical.* The conclusions are reached step-by-step in vertical thinking. Each step has to be valid, defensible and firmly connected to the preceding one. Anything that does not fit within the frame of reference, or is conside-red to be erroneous anomalities and natural noise, is excluded.

In lateral thinking it is not necessary to proceed in this sequential manner. Instead it is possible to jump ahead to a new point, as long as the gaps are filled in afterwards. Paths that seemingly lead the wrong way can be followed in order to reach the right conclu-sions. Another important feature in lateral thinking is the attempt to generate alterna-tive approaches, whereas vertical thinking tries to select the, ostensibly, best approach. "You cannot dig a hole in different places by digging the same hole deeper." (de Bono 1986 [1970]:12)
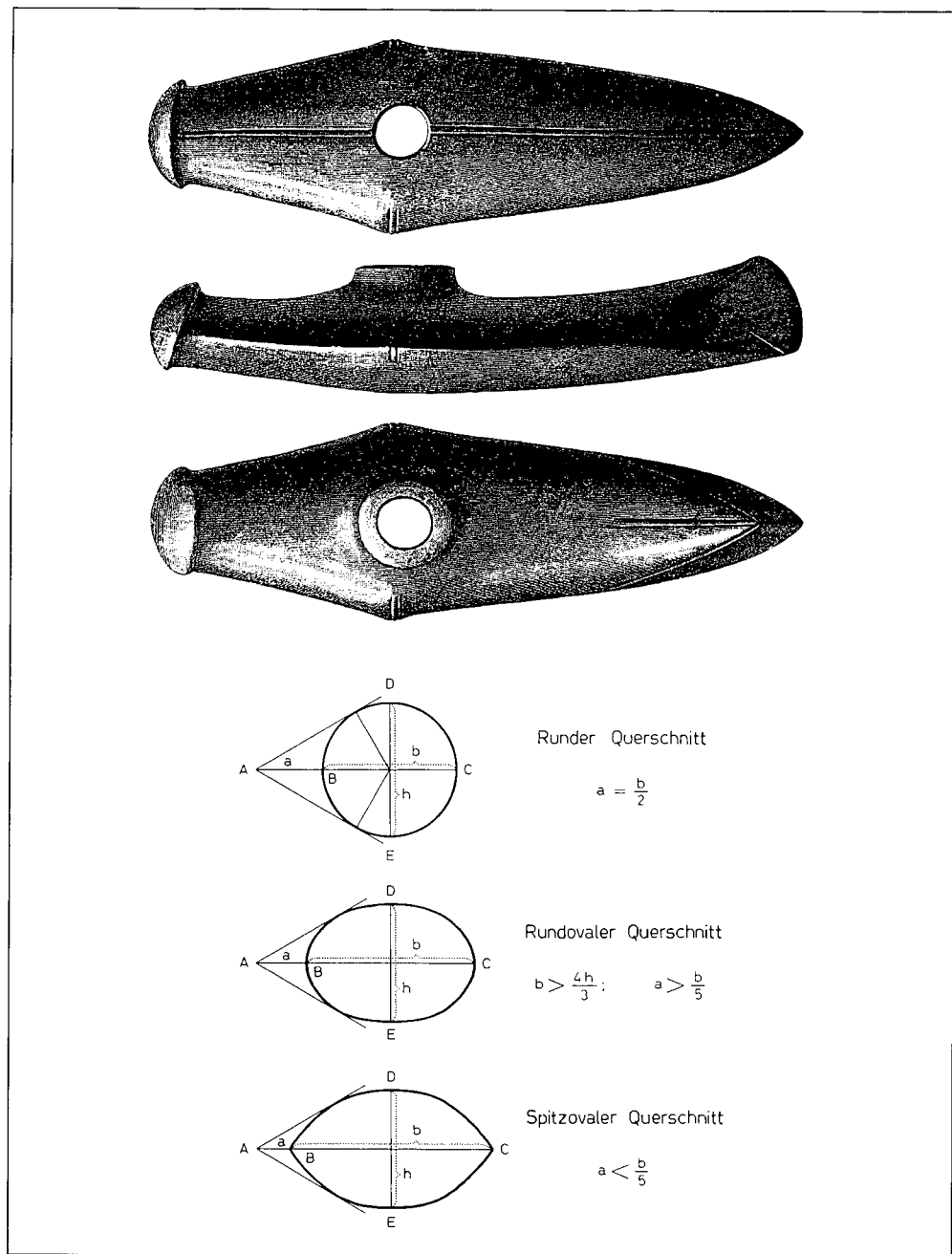
Runder Querschnitt

$$a = \frac{b}{2}$$

Rundovaler Querschnitt

$$b > \frac{4h}{3}; \qquad a > \frac{b}{5}$$

Spitzovaler Querschnitt

$$a < \frac{b}{5}$$

Fig. 5. The difference between an intuitive, synthetic and qualitative approach on the one hand, and an analytical, quantitative on the other, can be exemplified by comparing Oscar Montelius' and Mats P. Malmer's typologies. Montelius' typology is based on an impressionistic study of the objects, whereas Malmer's is based on quantifiable data, restricted to a set number of parameters (Magnusson-Staaf 1996, Montelius 1994 [1917], Malmer 1962, 1975:6). (Ill. from Montelius 1994 [1917]:23, Malmer 1975:174)

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