Evolution of bow-arrow technology

by

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Thesis abstract

This thesis examines the development of bow-arrow technology in terms of modern evolutionary theory. Previous approaches that propose functional-adaptive technological trajectories are critiqued. Different theoretical approaches towards technology and associated units of analysis are examined. Behavioural ecology, evolutionary archaeology, and dual inheritance theory are shown to hold most promise for explaining trait-lineages in a given technological tradition. Previous approaches to bow-arrow technology are analysed, and an evolutionary archaeological methodology appropriate for examining lithic armatures is presented. Environment, historical contingency, selection, drift, population dynamics and social learning mechanisms are seen as key complex factors requiring case by case examination.

An evolutionary case study with nine temporally, geographically, and culturally related stratigraphic phases containing a total of 3600 complete lithic armatures from the south Scandinavian middle Mesolithic (c. 6600-5400 BC) is presented. The phases are described in terms of associated fine-grained archaeological data and previous interpretations. A Bayesian chronological framework is constructed for the case study, using modelling facilities in the OxCal calibration package. This method time-steps and calculates relative occupation durations of point bearing phases in terms of available archaeological and radiometric data. The chronological model covers the culture-historical periods termed Blak, Kongemose and Early Ertebølle phases. The validity of previous typological interpretations of projectile point sequences is questioned in light of these results.

The nine time-stepped lithic armature assemblages are then analysed to describe inter- and intra-site point trait variation. A linked series of descriptive and multivariate statistical techniques identify key morphological attributes that summarise trait variation within and between phases. Variation is graphically represented and related to different social learning populations, reduction strategies, and engineering constraints. A remarkably long-term homogenous pattern of complex projectile point manufacture is found for the Kongemose phases, compared to the temporally bracketing Blak and Ertebølle phases. Faunal, climatic, and population level factors are then modelled to account for variation and stability of the case study's armature traits. Faunal data from the Tågerup and Segebro sites, spanning the case study period, are examined for possible diet breadth changes, in relation to point-trait variation. No functional relationship is found between point-shape and potential target-prey.

A population model is then constructed in OxCal using all published south Scandinavian radiometric data from the final Maglemose to the final Ertebølle cultural phases. A simple model of landmass reduction, forestation cover and mammalian population density levels demonstrates reduced land mass alone would not significantly affect human population levels - even with relatively high human population densities. Holocene $\delta^{18}O$ and $\Delta^{14}C$ data is used as a proxy for contemporaneous climatic fluctuations. These proxies are plotted and superimposed onto the population graph.

A correlation between climate change, population fluctuation, and projectile point technology is found. As changes in point morphology and lithic reduction strategies coincide with apparent regional drops in population, drift processes may account for some variation in point-shape.

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Preface

This project originated from my MA dissertation, which looked at bow-arrow technology in terms of inter- and intra-group conflict in the Greek Neolithic (Edinborough 1999). The qualitative results of the dissertation led me to question the role of different bow-arrow technologies elsewhere in history and prehistory, and the effects that they had on the people and groups that used them. Giving a central role to a specific technology was not enough; it became clear that to explain technological changes, a more holistic approach was required. The relationship between a diachronically changing environment, fluctuating populations, and cultural innovations and losses, were clearly key issues that were not being looked at in a coordinated manner.

Cross-cultural ethnographic and historical evidence strongly suggested that bow-arrow technology was a particularly important weapon-system, especially in terms of potential changes in the ranking of dietary resources, and the potential for increased rates of inter- and intra-personal violence. It seemed logical to believe that this was also the case in prehistory, and that with enough ingenuity, the underlying cultural processes concerning the development of bow-arrow technology might be identified, using the evidence of the archaeological record. It became clear that there was already a developed body of theory that had great potential for technological studies, one originating in the life-sciences, and gathered loosely under the umbrella of evolutionary theory, inspired by Darwinian principles concerning descent with modification. It seemed reasonable to say that, where they addressed the residue of past human behaviours on a technological case by case basis, Darwinian theoretical models had considerable explanatory power.

If I wanted to test the potential of these new evolutionary models, a much more comprehensive archaeological data-set was required, one suited to a thorough quantitative analysis, rather than the handful of arrowheads that was used in the MA project. Returning from fieldwork in Greece and Turkey in 2000, I commenced what I still see as a rather unusual, and exciting PhD. An initial year of theoretical research into evolutionary explanations of cultural processes led me to study in the United States for two months in September 2001, where I was based at the University of Columbia Missouri, thanks to a chance meeting with Dr. Mike O'Brien at a conference in UCL. When in Missouri I attended a series of Dr. Lee Lyman's ground-breaking evolutionary archaeology classes, and studied a vast collection of archery related artefacts, at the anthropology department's Grayson archery collection. By the end of my visit, it was clear that US scholars have been developing a complex array of different analytical methods to analyse arrowhead assemblages, both quantitatively and qualitatively, which could be very useful when applied to Old World datasets.

Upon returning to London, I began to search for an appropriate set of archaeological assemblages. When looking for the best available environmental context, in conjunction with a comprehensive data-set relating to bow-arrow technology; southern Scandinavian archaeology clearly offered the most potential. Five months of Scandinavian based research during the summer of 2002 armed me with a very large amount of unpublished arrowhead data, and a great deal of associated published and unpublished scholarly work. It also gave me a desire to repay the many Danish and Swedish archaeologists, museum curators, and academics who invested me with their trust, with a significant project.

Fundamentally, and despite my obvious interest in bow-arrow technology, this thesis became a methodological exercise to demonstrate how an integrated series of evolutionary models can be used to re-evaluate the material record. The methodological journey has proved an enlightening experience, whilst the results and conclusions have proved equally challenging. Evolutionary models of cultural behaviour are usually tested using the synchronous time frame of the anthropological record. There are currently too few diachronic evolutionary archaeological studies, and sadly, very few indeed that go into the fine-grained detail presented here. A current strength of archaeology is the surprising amount of excavated data that is already expertly recorded, and sitting in extant museum collections, just crying out to be rediscovered and reinterpreted. Surely the object of archaeology is not only to describe objects and preserve them, but to use theory to explain distributions of objects through time and space.

The theoretical essence of this thesis, and the central role that is given to technology, is at first sight against the grain of many traditional archaeological approaches and interpretations. However, as a new and recently developed body of theory is being used here; this is to be expected. I would argue that this project, in various ways, builds on the distinguished work of many others, and it is hoped that this will become very clear to the reader. In terms of theoretical archaeology, the post-modern alternative seems to me to be an intellectual exercise that, in the long-term, will prove somewhat of a methodological full-stop. Hopefully, this project does not prove an end in itself, but is instead the beginning of many holistic evolutionary studies; projects that will position various technologies at their centre. This seems a sensible programme for future research, not just for theoretical reasons, but because of the huge number of unstudied artefacts currently filling many an obscure museum storeroom, and the fact that lithic technologies were so ubiquitous for the vast part of human prehistory.

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This thesis would not have been possible without the generosity and kindness of many people, too numerous to mention here. It follows that any advice they have given has not always been followed, and all errors in this thesis are entirely my own responsibility. The following organisations and individuals require a special mention. The Arts and Humanities Research Board (AHRB) studentship provided the funding for me to undertake this research project. My primary supervisor, Prof. Stephen Shennan, director of AHRB Centre for the Evolutionary Analysis of Cultural Behaviour (CEACB), must be especially thanked for providing the inspiration for this project, and for his great patience in guiding my transformation from classicist, to evolutionary inspired archaeologist. My secondary supervisor Dr. Andrew Garrard has been similarly accommodating with me over the past four years. Dr. Dominic Rathbone of King's College London, my undergraduate supervisor, gave me the confidence to carry on my studies, despite my immediate postgraduate defection to University College London (UCL). Dr. Cyprian Broodbank at UCL steered me through my first term of doctoral research. Cyprian's teaching, enthusiasm, and the fond memory of three blazing fieldwork seasons spent on the Greek island of Kythera under his direction, remains a powerful motivation for me.

Dr. Roger Matthews, now at UCL, then director of the British School of Archaeology in Turkey, gave me an inspirational field season, as part of Project Pathlagonia in 2000. Roger was instrumental in arranging permission for me to look at Turkish and Mongolian archery tackle in Cankiri Museum in northern Turkey. Just prior to my return to UCL, after surveying Palaeolithic tool scatters, a Bronze Age Palace, and many an Iron Age hill fort, Roger transformed the team into an impromptu guitar-band in a music shop in Ankara, and then paid for my subsequent hospital fees; for all of this, I cannot thank him enough.

The members of the UCL 'Culture Club' research group of the CEACB, are thanked for a constantly challenging intellectual environment; one that allowed my own perspectives to evolve. Dr. Mark Collard must be thanked for the most relentlessly thorough, and ultimately useful, criticism of my initial work. Mike Charlton has constantly proved a tough academic sparring partner, where few other contemporaries seem interested in theory, let alone evolutionary theory. Prof. Ole Grøn, thank you for your encouragement, unpublished MA thesis, and enthusiasm. John Meadows is thanked for his technical advice and challenging criticisms concerning the OxCal ^{14}C chronological modelling developed in this thesis, and for our many chronological discussions. Sue College patiently tutored me through the eccentricities of the CANOCO correspondence analysis program. Prof. Clive Orton kindly advised me concerning the use of discriminant analysis statistics. At the beginning of my research, Dr. Peter Rowley-Conwy of Durham University kindly gave me some initial advice, references, and contacts for southern Scandinavia. I must also thank Dr. Richard Carter for some initial information, and the unusual (and hopefully not too dangerous) afternoon x-raying Mesolithic mandibles in the Copenhagen Zoological Museum.

From the United States, Dr. Mike O'Brien, Dr. Lee Lyman, and the staff of the anthropology department at the University of Columbia, Missouri, (UCM) must be thanked for their generous hospitality. They gave me free accommodation at the University in 2001, whilst I spent two months studying the world's biggest collection of archery artefacts in their department's Grayson archery collection. Bill Grimm of UCM generously gave me the confidence ellipse program which he wrote for Excel. Dr. Mike Shott, of Iowa State University, gave me some incisive questioning in my MPhil/PhD upgrade, and some very useful guidance concerning quantitative approaches to New World projectile technology.

During my five months of research and fieldwork in 2002, all the Scandinavian academics I approached proved fantastically generous with their advice and data; no one refused me access to their collections. In Denmark, as well as the staff of the prehistoric department of the National Museum of Denmark, Peter Vang Petersen must be especially thanked for steering me towards the largely unpublished Kongemose Mesolithic phases, for allowing me to study his unpublished dissertation on Mesolithic chronological problems in south Scandinavia, and for providing me with access to the museum's stunning prehistoric collections. Also, thank you to Dr. Anders Fischer at the Danish Forest and Nature Agency, Dr. Eric Brinch-Petersen at the University of Copenhagen, and Prof. Kim Aaris-Sørensen of the Copenhagen Zoological Museum.

In Sweden, Prof. Lars Larsson of the Archaeological Institute of Lund University gave a recommendation that helped me gain access to many Swedish collections. The staff of the Swedish National Heritage Board in Malmö and Lund, especially Dr. Elisabeth Rudebeck, must be thanked for tracking down the elusive Segebro projectile points, and for arranging my extended stay at the aptly named "Hotel Sparta" at Lund University. Hampus Cinthio and Ylva Olsson of the Lund Historical Museum and the Gastelyckan warehouse-store; thank you for your help in locating various collections, and for providing me with desk space. In Lund, Dr. Per Karsten and Dr Bo Knarrström kindly gave me unprecedented access to the Tågerup excavation material, desk space at the Landskrona Historical Museum, and a startling amount of Swedish hospitality. Under Bo and Per's careful supervision (and the amused eyes of their entire fieldwork team), I dug and sieved an unforgettable first Mesolithic square-metre.

To the following people, I owe a special debt. In Copenhagen, Sophie Madsen and Mikkel Venge, thank you for the use of your wonderful flat; I will replace your bicycles. At the Institute of Archaeology in London, thank you to all my research colleagues, and especially my fellow basement survivors from the IoA room B52. To Thomas Belton of News International, thank you for the proof-reading, and the eye-opening introduction to journalism. To James Preston of the Ministry of Defence, thank you for your expert opinions on the evolution of various projectile technologies, both ancient and modern. To Christopher Lai and Dr. Steven Leppard, thank you for the knowledge that allowed me to study without financial burden. To Grahame Tinsley, Viral Patel, Ajay Rai, Stephanie Almas, Alp Almas, and not least Trina Spurgin and Meg Harrison; thank you for all your kindnesses, generosities, and accommodations.

Finally, I would like to dedicate this thesis to the memory of my remarkable parents, Doreen and Kenneth Edinborough.

Chapter 1. Evolution of technology

1.1 Thesis objective

The objective of this project is to construct a linked series of models from a case study to identify key archaeologically recoverable evolutionary processes relating to specific bow-arrow technological trait lineages, and to explain how these processes can interact and affect a given prehistoric population. It is proposed that this method requires a case by case holistic ecological approach at both trait and population level, as broad scale functional-adaptive statements about human prehistory at wide geo-temporal scales require more careful qualification than previously given. To achieve these ends, the south Scandinavian Mesolithic was chosen as the case-study, due to exceptionally fine-grained archaeological evidence, a renowned tradition of research into peoples who used bow-arrow weapon systems throughout prehistory, and not least the remarkable generosity of Scandinavian researchers regarding use of their data.

1.2 Introduction

The thesis is presented in seven chapters with relevant figures and tables given after the text, and with an attached appendix CD, containing all data used in this project. The remainder of this chapter examines previous theoretical approaches towards technological evolution that were ignorant of, or demonstrably underestimated the complexity of evolutionary theory. Key issues relating to cultural units of evolutionary analysis, e.g., sorting mechanisms (selection and stochastic drift), modification mechanisms (random innovation processes), and cultural transmission and differential replication mechanisms (social learning constraints), are summarised. Memetic (Dennett 1995), behavioural archaeology (Schiffer 1995; 1996), evolutionary ecology (Smith and Boone 1998) evolutionary archaeology (Lyman and O'Brien 1998) and dual inheritance approaches (Bettinger Boyd and Richerson 1985; 1996) are critiqued. Units of analysis from both materialist and essentialist perspectives are compared (O'Brien and Lyman 2000) and a strategy is formulated for dealing with data related problems. Inappropriate or inconsistent units of technological analysis relating to mode, tempo, and scale of evolution are seen as key limiting factors in previous paradigms. Technological explanations impossible to test archaeologically are exposed as either fundamentally flawed or impractical. Environmental and population dynamics are causally related to specific technological transmission mechanisms. Recent theoretical developments from behavioural ecology using foraging theory (Fitzhugh 2001), evolutionary archaeology using seriation and cladistics (O'Brien and Lyman 2000), population genetics and dual inheritance social learning theory using formal mathematical models (Boyd and Richerson 1985; Bettinger and Eerkens 1999; Henrich 2004), are shown to currently hold the most explanatory power concerning bow-arrow technological evolution. A refined technological model adopting a holistic approach to exogenous environmental phenomena, and endogenous population processes, in terms of specific evolutionary processes is proposed (Neiman 1995; Shennan 2000, 2003; Henrich 2004). At the end of this chapter, a summary of the remaining thesis chapters is then presented.

1.3 Early technological studies and evolution: Hesiod to Marx

Technology is simply defined by the Oxford Reference Dictionary as the study or use of mechanical arts and applied sciences. The academic study of technology is complex and diverse as it is vast, Rogers notes in his work on historical diffusion of innovations some 3900 titles under 16 categories (Rogers 1995, 443-501). In the western tradition since Hesiod (c. 700 BC), writers have classified the human condition in terms of technology (Works and days, II, 170-201). Hesiod's instructive tale to his brother described a linear deterministic technological descent, idyllic golden age followed by morally degenerating silver and bronze ages, ending in his own amoral age of iron. Converse views of innate human propensity causing technological progress can be attributed to the Roman Epicurean philosopher Titus Lucretius Carus (98-55 BC). Lucretius proposed a three age technological system of stone/wood, bronze and iron, and described how early technologies helped primitive subsistence in a manner that was determined solely by natural rather than supernatural causes, ever since man "hunted the woodland beasts with flung stones and with the ponderous heft of gnarled branch..." (*De Rerum Natura* 5.1002).

Technological evolution could only be speculative prior to development of relative dating techniques. Scandinavian scholars led the way. A chemistry lecturer from Lund, Dean Magnus Bruzelius, suggested that the Swedish passage grave site of Åsohogen should be assigned to a distant antiquity of the Stone Age in 1822 (Karsten et al. 2004, 11). In 1836 the Dane Christian Jürgensen Thomsen developed a tripartite chronological scheme based on technological divisions, dividing the National Museum collection in Copenhagen into Stone, Bronze and Iron Age sections for public consumption. Thomsen's famous typological method relied on relatively ordering styles of closed finds, characteristic of different periods. The resultant catalogue was a chronological sequence based on technological and stylistic trait differences that proved monumentally influential (see chapter five). Thomsen's work developed into a five stage progressive evolutionary scheme, a reversal of Hesiod's earlier sequence (Gräslund 1974, 1987).

Herbert Spencer's (1820-1903) notion of directed evolution in his *Principles of Psychology* profoundly affected approaches to technological evolution (1855). This classical evolutionary school, i.e., Spencer, Tylor and Morgan (see below) utilized the comparative method, which compiled and compared data concerning technological stages of usually pre-state and non-state peoples, with the aim of attributing stages of actual historical evolutionary sequences (Sanderson 1990, 37). Their unit scale was of culture as a whole, cultures were ordered onto a linear evolutionary scale rather than seen to comprise multiple lineages of cultural-technological traits (contra Steward 1955, 12). Written at the peak of Britain's industrial revolution, Spencer's optimistic work was the archetypal antithesis to Hesiod's miserable 'descent of man'. His evolutionary scale was gradual rather than revolutionary, and like Marx (see below), he championed individualism as an inevitable causal mechanism for cultural change described as '...that grand progress which is now bringing humanity onwards to perfection' (Spencer 1855, 620). Spencer, like Tylor and Morgan, based generalizing theories on weak anecdotal grounds, and despite some astute technological observations was undermined by later empirical case studies demonstrating local variations and divergence from a unilinear direction (Steward 1955, 15). During military service in 1858 General Augustus Lane-Fox Pitt-Rivers (1827-1900) undertook one such study, concerning the technological history of firearms as part of a committee to select a new side-arm for the British army. His ground breaking method made no assumptions about progress, instead he studied specific lineages of innovations, rather than how general trends occurred in some overall progressive developmental scheme. Results demonstrated that whilst guns indeed became more complex over time, mechanical complexity did not follow a unilinear direction - most of the huge numbers of innovations had led to evolutionary dead ends. In one empirical study, Pitt Rivers demonstrated that cultural evolution need not be progressive or inevitable (Pitt-Rivers 1858, Trigger 1998, 81).

Urban squalor resulting from contemporaneous mass industrialization began to shake widely held notions of inevitable technological progress initially encouraged by Spencer. However, motivations for studying cultural evolution often involved explosive combinations of increased nationalism in a less stable economic climate, and this had deleterious biasing affects on subsequent technological studies. In contrast to Darwinian views of evolution influenced by the Malthus's (1798) mechanistic population level observations, Karl Marx proposed a linear technological progression in his preface to *The German Ideology* (1845-6) describing tribal, ancient, feudal and capitalist modes of technological production (see Sanderson 1990, 63). Later, in *Capital* (1867/1967), he refers to societal stages in a less than explicit manner throughout, which although unacknowledged still owed much to Spencer's earlier work. In later life Marx compiled many notes on Lewis Henry Morgan's book *Ancient Society* (1877) which proposed a tripartite staged technological system (Sanderson 1990, 63). Morgan's stages consisted of Savagery and Barbarism, each of which he subdivides into three, then finally civilization. His scheme is in fact seven stages, generally typed by characteristic technologies. Morgan's 'upper status of savagery' starts with the development of bow-arrow technology, and finishes with the invention of pottery. Marx and Morgan's cultural evolution placed analytical emphasis way above the unit scale of artifact, and towards the societal scale in terms of 'modes of production', unlike Thomsen's and Pitt Rivers, who both accounted for specific technological traits. The latter two authors had more intimate knowledge of historically contingent complexities effecting artifact lineages, which could explain their more particularistic approach to classification. In Marx's developmental schema, primitive products were transformed into more complex ones at different stages of linear technological development - through a struggle between stratified layers of society. Class struggle was the causal mechanism for technological evolution. Productive labor and resultant artifacts were harnessed by increasingly stratified societies, which inevitably progressed from a primitive technological condition (Marx 1867, section four). Marx had no explanation for pre-state or non-state technological development. Despite later sympathies with Darwinian mechanisms, Marx was too inconsistent in his explanation of technology. Ultimately Marx took a teleological position where socio-technological change was preordained as proposed by Hegel (1770-1831) his major philosophical influence (Trigger 1998, 93). Marx held an overly anthropocentric view of causal mechanisms affecting technology. His ideas were ungrounded empirically despite a late correspondence with Darwin indicating a great sympathy with his work (Sanderson 1990, 70-71). Like most contemporary scholars he relied dogmatically upon man's innate ingenuity and evolutionary destiny as causal for technological change. The political fallout in the 20^{th} century was profound. Despite Boas' legacy of paticularist studies that generated vast bodies of empirical evidence, history saw the official Soviet adoption in 1952 of Morgan's social evolutionary sequence. The Soviets, like many other contemporaneous ideological factions, failed to question technological assumptions that Morgan erroneously made the previous century (see below; Steward 1955, 15).

1.4 Culture Historical evolution and technology

In the 1880's Oscar Montelius refined Thomsen's earlier technological sequence by developing a more explicit seriation, an internally coherent ordering of different technologies based on Enlightenment notions that technology progressively developed due to human inventiveness rather than any Darwinian mechanism. Not all of Montelius' proposals were unilinear. He noted different geographically circumscribed cultures developed at different technological tempos, whilst technological features from Bronze Age fibulae from Scandinavia and Italy eventually merged into a pan-European variety. This cultural reticulation was made more explicit by Kroeber (see below). Montelius also pioneered technological diffusion theory with the *ex oriente lux* 'light from the east' school of archaeological thought. This saw diffusion of technologies and cultural attributes from cores to peripheries as a causal mechanism for cultural change, and was seen by many as evidence for non-biological mechanisms of cultural transmission (see below Gräslund 1974; Klindt-Jensen 1975, 87-96; Renfrew 1973, 36-7; Trigger 1989, 157, 160).

Like Morgan, Edward B. Tylor (1871) also proposed a unilinear progressive cultural evolutionism through technological stages, although he was more concerned with particular culture histories than general evolutionary schemes (Sandersen 1990, 13-15). In the US, Boas took a strong anti-evolution stance in reaction to the comparative method of the classical evolutionists (Boas 1896) and by the end of his career decided that culture was to complex to be governed by any cultural laws (Boas 1932, 257). However, in Europe increasing amounts of empirical evidence was being collected, and economically destabilized nations looked to evolutionary and archaeological explanations for their early origins. Geographically and temporally restricted distributions of artifacts began to be labelled as cultures and ethnic groups by various patriotic archaeologists around the same time, fuelling inflammatory notions about cultural and racial superiority (Trigger 1980). Rather than diffusion, notions of cultural invasion and replacement were postulated across Europe as causal for technological change, a view fanatically adhered to by the German Kossina (1911), and later appropriated by Nazis as justification for ethnic subjugation and genocide. In fact, Kossina looked to the Early Mesolithic Maglemosian culture in Schleswig and Holstein in the southern Jutland peninsula, taken by Prussia from Denmark in 1866, for evidence of the first Indo-Europeans/Germans (see below).

Classical evolutionary authors indirectly influenced V. Gordon Childe (1951), Leslie White (1949; 1959) and subsequent generations of anthropologists and archaeologists such as Service (1962), all of whom could be termed materialists who focused on the role of technologies in society (see below). Although much has been read into Childe's materialism, he avoids stating explicit causal mechanisms for technological change - other than man's ability to create his own history, as evident in the title of *Man Makes Himself* (1936). Childe's detailed empirical descriptions often obliquely defer to Marx for causal explanations such as science, social forces of production, and economic conditions. In his obscure *Progress and Archaeology*, Childe prefers to refer to Thomsen's three ages as stages (1944, 5), broadly accepts Morgan and Engel's notions of savagery, barbarism and civilization with the caveat that they don't have exact prehistoric correlates, whilst proposing population expansion as causal for development of writing technology, through increased numbers of craftsman and merchants which then 'produced a qualitatively new entity, namely the city' (1944, 11). As specific social conditions are equated with stone, bronze, and iron tools, it is difficult to describe Childe other than a technological determinist despite Trigger's contrary view, and despite his lack of direct reference to causal mechanisms (Childe 1936, 7, 202; Trigger 1998).

Different authors subsequently adopted different approaches to technological evolution, although most were teleological. In contrast, Alfred Kroeber, surprisingly a student of Boas, saw cultural evolving in a way analogous to biological evolution, through competition of ideas, but unlike biological mutations, innovations of ideas were non-random; they were the product of social conditioning. For instance, the history of a technological lineage enabled scientists to make the same discovery purely by working in the same constrained social tradition (Kroeber 1948: 341-3). As Trigger points out, Kroeber inadvertently supported Marxist views of innovation - also caused by social conditioning (Trigger 1998, 115).

Julian Steward was a paticularist, but unlike Boas, he saw the value in using evolutionary methods – he was a student of both the generalist Alfred Kroeber, and the methodologically cautious Robert Lowie. Steward adopted a nonlinear, case-specific, empirical, and ecological approach to culture and called for archaeologists to work with ethnographers (1938). In comparison with White (see below), Steward was very cautions in applying evolutionary theory, avoiding gross generalizations. He saw multi-linearity and historical contingency as key to understanding technological change '…no known principle of cultural development could have predicted specific inventions such as the bow…' (Steward 1956, 59-60). Steward's societal scale of evolutionary analysis embraced Wittfogels theories of environmental circumscription and introduced the local environment as a causal variable, an approach that came to be known as culture ecology (White 1955, 36; Sanderson 1990, 90). Grahame (J.G.D.) Clark similarly posited that all aspects of cultures were influenced to some degree by ecological constraints, and archaeological finds had to be examined from a functional perspective. He saw technologies as shaped by material constraints that could be understood through the natural sciences, and proposed that economic factors constrain rather than determine technologies (Clark 1936). Leslie White, in contrast, formulated a law of technological determinism, which stated that culture evolves as the amount of energy per capita increases, or as the efficiency of putting energy to work is increased; this was described as Culture = Energy x Technology (1949, 390-1). This formulaic expression of technology again gives primacy to human inventiveness, and optimistically ignores any effect of ecological constraints on technological evolution. White, following Durkheim, saw culture as the unit of analysis, only understandable in its own terms and definitely not at the individual or trait level (White 1949), a view vehemently rejected by Steward on empirical grounds (1955, 5).

Common to social evolutionary thought has been the unqualified notion that certain technologies are simple, and others are complex and indicative of 'non-primitive' societies. Service was particularly guilty of assuming simple adaptive progress by inaccurately defining the bow-arrow as an inherently 'simple' technology (Service 1966: 27; see chapter two). Authors adopted crude units of analysis - the culture as a whole - instead of the study of precise lineages of cultural phenomena (O'Brien and Lyman 2000). The problem was previously countered by Pitt-Rivers' empirical case study approach, which demonstrated an artifact-trait level analysis could provided counter-intuitive results, where a teleological position cannot.

Despite Steward's ecologically contingent approach, and White's determinism, the culture historical approach to technology was mainly a descriptive enterprise, one categorizing artifact-variation into cultures and periods empirically, but with a self-referential circular causal methodology wherein typological similarity denoted historical relatedness. There was not enough explanatory power – causal mechanisms were too speculative to be convincing. Explanation of cultural patterns required a shift in analytical scale to that of cultural processes in tandem with more precise quantification of empirical data (O'Brien and Lyman 2000, 164).

1.5 Processual evolution and technology

New Archaeology of the 1960's and 1970's rebelled against theoretically stale culture historical typological methods. Influenced by White, Lewis Binford was chief protagonist, and he called for explicit scientific method to replace theoretical inertia (1962). Binford wanted archaeology as anthropology, where he believed ethnographic analogues could be found for archaeological human behavior and cultural phenomena. The processual program undertook experimental studies to determine use of prehistoric artifacts, coupled with ethno-archaeological research where general models of culture were seen in their entirety as an adaptive system. Technology was seen as functional, in that it was honed by natural selection and contributed to the adaptiveness of the culture. To be scientific as Binford saw it, archaeology had to adopt strict hypothetical-deductive method, so research could link modern human behavior directly to the past. Binford proposed 'middle range theory' to link dynamic conditions that produced archaeologically recognizable effects to general theory comprising of the processes that were responsible for organizational changes and variation in living systems (Binford 1977, 7; see below; O'Brien and Lyman 2000, 172-173). Critics of Binford's subsequent research noted construction of overarching general theory, e.g., a nuanced evolutionary theory, was ignored at the expense of developing middle range theory, from observable human behavior (Sablov et al. 1987, 203). Michael Schiffer (1995) argued against the whole paradigm as the archaeological record could give a distorted reflection of the present, although his own empirical approach was criticized as method divorced from theory (see below).

Theoretical emphasis shifted towards mechanisms involved in culture process, rather than culture description. However, the processualist evolutionary explanations that followed were theoretically inadequate. Binford saw culture in much the same way as his tutor Leslie White did – as man's extra somatic means of adaptation, and at the unit level of the artifact. Adaptation is only one aspect of an evolutionary reconstruction – and an adaptionist paradigm is not always the most informative way of analyzing the long term material record (see below). It will be argued that archaeology with its diachronic status should be seen as archaeology following David Clarke's (1968/1978) systematic approach. Clarke noted specific strengths of the discipline that separated it from anthropology. He adopted a view of time as a materialist continuum like a braided cable (Clarke 1968, 12), where objects are in a constant state of becoming - as opposed to objects being 'fixed currency' in an anthropologically synchronous time scale. Following Clarke, and more recently O'Brien and Lyman (2000), a fundamental difference is seen between *essentialist* units, such as the whole artifact, which are viewed by typologists as fixed like units in classical physics and chemistry, and *materialist* units which are phenomena that cannot be discrete kinds and are constantly becoming something else (O'Brien and Lyman 2000, 401).

Binford's simplistic emphasis upon functional adaptation, with natural selection as the only sorting mechanism, is still echoed by the evolutionary/behavioral ecologists' approach to culture. If Lyman and O'Brien are to be believed, overemphasis on connecting data to short-term synchronous middle range economic models may be throwing the baby out with the bathwater (see below).

1.6 Recent technological studies and evolutionary theory

Current approaches to technology need not be evolutionary in nature. The majority are best described as social Pfaffenberger (1988); Appadurai (1986); most of Lemonnier (1993), except Petrequin (1993); Van der Leeuw (1989); economic - following Marx (1867/1967), 'business management' following Rogers (1995), or historical or comparative (most of Ziman 2000). Archaeological explanation regarding specific lithic technologies will be discussed next chapter. However, some authors have used explicit Darwinian mechanisms to explain technological change with success. Basalla (1988) is one such author; his work will now be discussed in detail.

Basalla places an emphasis on history of technology and the associated effects of selection in his *Evolution of Technology* (1988). This ambitious wide-ranging book presents historical contingency and selection as key evolutionary forces affecting technological change. Like Marx, Basalla sees technological transmission at the wider analytical scale of 'production mode', rather than at the unit scale of the artifact, or at the trait level within artifacts. However, like Boyd and Richerson (1985), Basalla sees dual genetic and cultural inheritance systems interacting to generate artifact diversity in a cultural sphere which is not pre-determined. Unlike Marx, Basalla attacks simplistic common sense explanatory theory such as 'necessity being the mother of invention' in the cultural-material inheritance sphere. Instead, selection is posited as the causal mechanism that changes artifact lineages (1988: vii). Basalla's cultural selection process is seen to act most clearly in times of warfare, where the results are most historically dramatic (1988:158-160). Only broad scale evidence at the artifact-production scale are presented to support these views, but Basalla reasonably states that new kinds of made things are never pure creations of theory, ingenuity or fancy – in other word artifacts are historically contingent. This signifies a clear break with the Marxist tradition that places human intent as the pivotal casual evolutionary mechanism. Following Schumpeter (1961), and Elster (1983), selection is also seen at the active individual agent level, with entrepreneurs making choices to shape the world 'as they see fit' (1988, 204). Whether Basalla's agents need to be conscious or unconscious (or both) to affect differential persistence of rates of artifact-trait variation for selection to act on, is not clear. The role of other evolutionary mechanisms also remains enigmatic, although by invoking a Darwinian framework, agent motivation *must* be to consciously or unconsciously increase biological fitness. Whether this is at the group or individual level is again unclear. Even if Basalla is correct, his theory has only limited amount of archaeological mileage. At the state-level of analysis, Basalla's method shows some analytical promise; however, archaeologists cannot identify individual agency or behavior prehistorically, as whole artifacts, let alone whole weapon-systems, rarely exist in sufficient numbers for meaningful comparative analysis. Basalla fails to account for environmental constraints that determine the selective environment. However, he destroys notions of deterministic technological progress and inevitability posited by Spencer et al., which ignore effects of history and selection. Basalla steers too far from a population trait-level perspective that Darwin proposed in the *Origin of Species* (1859) to be useful for prehistorians, but by adopting an artifact orientated analysis accounting for contingency and selection processes, Basalla makes a limited theoretical breakthrough.

Michael Schiffer's (1995; 1996; 2000)'behavioral archaeology' research programme exposes many of Basalla's short comings concerning technological evolution (1996, 2000). Schiffer adopts an approach similar to Pitt-Rivers (1858), to illustrate Basalla's shortcomings concerning any potential counter-intuitive technological evolution. Through empirical study, Schiffer examines the failed 'take-off' of electric cars - opposed to the success of the petrol engine versions c.1895-1920. Widespread intuitive beliefs concerning technology and particularly the demise of the electric car are termed by Schiffer as *indigenous theories*. When these were surveyed amongst his student body, 95% of respondents named comparatively worse performance of electric engines, oil company conspiracy theories, or lack of capital investment as causal mechanisms for its failure. Each indigenous theory was then falsified and exposed as myths perpetuated by the pervasive influence of modern consumer society (Schiffer 2000, 81). Schiffer then assigned a three stage 'life history' to both automobile types. This method is analogous - but less rigorous - than the quantitative way behavioral ecologists assign life histories to biological species (e.g., Hill and Hurtado 1996; Clutton-Brock 2002; see chapter six). No prior knowledge of respective automobile technologies was assumed. Each technological life-history stage was examined through archival study of product data designed to eliminate erroneous explanations. This is a version of the 'multiple competing hypotheses' method employed by ecologists. The product history stages were as follows, invention (creation of prototypes), commercialization (factories are created) and adoption (sale of product). The final phase, product adoption, showed most promise for explaining the 'take-off' of the petrol car, as the first two stages demonstrated very similar product histories for the competing types of automobile. Schiffer concluded behavior related peer pressure was the major factor for the demise of the electric car, and that this occurred due to chance rather than intentional design. Advertisers and manufacturers pitched the electric version as a luxury product in women's magazines aimed at America's 'horsey set' - even Henry Ford's wife Clara owned an electric model. The electric car failed simply because the blue collared middle class patriarchs had the most combined purchasing power at the time, and opted for the vehicle with the less feminine associations, rather than for any other reason (Schiffer 2000, 81). Schiffer concluded that living informants should be interviewed to compile more indigenous theories fit for falsification. However his approach does not work for prehistoric technologies, as all informants are dead. Schiffer posits an informally stated prestige biased transmission mechanism that causally accounts for technological change in terms of population effects. His is a vague method compared to Boyd and Richerson's formal approach (see below), although, by adopting non-directional Darwinian population level explanation, the electric car can be seen as another evolutionary dead end, despite it actually being functionally superior to the petrol version at an early developmental stage.

The theoretical emphasis on human intent (willful or unconscious) affecting technology at the expense of all other extrasomatic mechanisms of change is a position perpetuated in evolutionary ecology today. Arguments still surround the extent to which human behavioral plasticity and willful problem solving circumnavigates selection processes, and the extent that this separates humans from other species for purposes of evolutionary analysis continue (Boone and Smith 1998; see below). Schiffer recognizes the often counter-intuitive role that random events play in cultural evolution; his study demonstrates stochastic processes can play a greater role than previously thought.

1.7 Units of technological analysis:
Cognitive Psychology, Replicators, Interactors, and Memes

Key to cultural transmission is cognitive psychology, the nature of the cognitive architecture of the human mind and the associated mechanisms underlying social learning pathways between individuals, and within populations of individuals. This first section will look at the different paradigms before useful cultural units of analysis are explained.

Memes, as proposed by Dawkins are direct cultural metaphors for genes. They can take the form of "tunes, ideas, catch phrases, clothes fashions, ways of making pots or building arches..." (Dawkins 1976, 206). The problem with memes is whether they have physical existence in the brain - perhaps in the form of a single biochemical signature, or whether they have a more complicated existence as series of interconnecting biochemical units. Perhaps multiple memes control a series of interconnecting biochemical units rather like *pleiotropy* or *polygeny* in genetics (see above). 'Phenotypic' (see below) effects of memes may be similarly complicated and difficult to analyze in terms of Dawkin's argument - if they do exist. However, Dennett optimistically proposes that one day 'a striking similarity will be found between brains storing the same information' allowing us to identify memes syntactically" (Dennett 1995, 341). This remains an empirical issue as even the 'mind as module' – a view Dennett champions, has yet to be resolved (Whitehouse 1994).

A simple definition of a meme is clearly difficult to reconcile. However, cultural units of inheritance issues were resolved to a degree by the philosopher David Hull who noted that evolutionary scales of analysis were erroneously viewed as fixed – going against the prevailing view in biology at the time which saw genes mutate, organisms selected, and species evolve (Hull 1981, 41). Hull theorized evolutionary forces could act on various scales. He also proposed a new system of evolutionary units of analysis by developing a theoretical inheritance mechanism using the terms 'replicators'- 'an entity that passes on its structure directly in replication' e.g., invisible memes, and 'interactors' – 'an entity that directly interacts as a cohesive whole with its environment in such a way that replication is differential' (Hull 1980, 318) i.e., visible through differential phenotypic traits. Hull proposed evolutionary analysis should be viewed as a hierarchical process, and that analysis must be carried out at scale specific unit level of interactors, replicators, and lineage. O'Brien and Lyman state that as genes can be seen as replicators and fossils can be seen as interactors, and as artifacts are phenotypic expressions (like teeth and bones), one 'type' of projectile point (an interactor) changing to another in a lineage, can represent a change in replicators. These replicators could in fact be Dawkin's memes, which manifest themselves as interactors (O'Brien and Lyman 2000, 242). The fitness of the individual manufacturing the projectile points might or might not have been affected by the change in projectile points – this is a separate empirical issue (ibid.). If O'Brien and Lyman are correct, differential distributions of interactors may be due to the vagaries of different transmission mechanisms – projectile points are not simply adaptations, but can also be independent of individual, or even group level selection, acting on people.

1.8 Neutral theory of evolution: cultural and technological analogues

Adaptationist paradigms place an overemphasis on the sorting role of selection and not enough emphasis on the role transmission processes. Any idea that DNA is always functional, and that selection always and strongly acts on DNA units of inheritance is patently not true (Gillespie 1998). Much DNA is termed 'junk' – it appears to have no immediately detectable function - and is transmitted stochastically. The importance of this essentially random information was recognized by Kimura in 1983, and formed the basis of the neutral theory of evolution. Population geneticists have made many recent theoretical inroads into evolutionary biology (Gillespie 1998), and have tended to construct formal models of evolutionary theory that can be tested using computer simulation and fast breeding populations, such as *Drosophilae*. They attempt to explain why there is so much genetic variability in natural populations. This is achieved through modeling and testing the effect on trait populations of a variety of evolutionary forces not just selection (Gillespie 1998, 19). These include the interaction between neutral genetic drift and mutation processes, which puts variation back into populations; and differential scale effects where numbers of traits can affect the degree of transmission fidelity. It is clear from population genetic studies that different types of selection can act counter-intuitively on a population, and these require modeling and testing. For instance, although directional selection is the type Darwin (1859) was proposing in *Origin*, stabilizing and disruptive selection have different effects on a population of traits over time (Gillespie 1998, 55).

Previously, cultural evolutionists have failed to account for technological variation and change through a narrow or ignorant view of potential explanatory evolutionary processes other than selection. Current evolutionary studies analyze the effect of genetic drift, the historical contingency of traits, and the mechanical constraint of evolutionary developmental pathways relating to transmission bias, at both biological human population level and cultural technological trait level (Boyd and Richerson 1985; Neiman 1995; Shennan 2002). The sheer diversity of approaches suggests that simple functional-adaptation explanations concerning technological transformations may be seriously inadequate. Each case has to be studied on its own merits (Shennan 2000). Evolution is demonstrably something you cannot generalize with catch-all statements such as Spencer's de-contextualized 'survival of the fittest'. Archaeologists who wish to apply genetic analogues to the cultural record have to be very wary of the theoretical problems concerning inheritance mechanisms in evolutionary biology and population genetics, and must define their units of analysis more carefully.

Stephen Shennan proposes that we can see drift effects at the population level of cultural transmission (see below), in terms of fluctuating demography affecting the differential persistence of social learned traditions (2000, 55). If a cultural population has a small effective size from the learning and teaching point of view, and a crucial teacher is lost, it is more likely to have a detectable effect in a small population than on a larger population of social learners. This was seen by Rivers in his (1926, 200) discussion of *'the disappearance of the useful arts'* in relation to loss of technological traditions in Oceania, where the canoe vanished when ecological factors were virtually identical between neighboring islands that had respectively retained and lost canoe technology. Selection need not play a part as, for instance, this could be a result of stochastic process. When a complex skill with an obvious material residue is ritualized and hereditary, such as the canoe or complex lithic technologies associated with certain projectile points, the effects of technological loss could be explained by a fluctuating prehistoric population of effective (those that pass on crucial skills) teachers and learners (Shennan 2002, 56; Bettinger and Eerkens 1999; Henrich 2004; see chapter six).

1.9 Recent paradigms for technological evolution

Recently, there has been a reaction against the theoretical inconsistencies of 'progressive' social evolutionists, and a series of competing paradigms have emerged that can help explain technological change. Although united under Darwin's theoretical umbrella, application of aspects of Darwin's principles have proved controversial, becoming the subject of fierce debate between competing theorists (see Lyman and O'Brien 1998, vs. Smith and Boone 1998). The role of memes, as the proposed units of cultural inheritance coined by Richard Dawkins and championed by Daniel Dennett (1995), has been shown to be no less problematic than simple adaptationist genetic explanations (see above).

The key 'Darwinian' approaches towards technological evolution are now examined, alongside the complementary range of evolutionary processes deemed here to be archaeologically accessible. Finally, a synthesis of the most appropriate methodology for the archaeological study of bow-arrow technology is proposed.

1.10 Human Behavioral Ecology and technology

Human Behavioral Ecology (HBE, or simply BE), also known as evolutionary ecology or 'adaptationism', began as a research program in the mid 70's following post World War II research into optimal animal behavior, with initial applications of Optimal Foraging Theory (OFT) directed towards understanding human populations' resource selection and land use in non-state societies (Chagnon and Irons 1979). This pioneered widespread use of economic models anthropologically, models originally developed in the context of previous non-human behavioral studies carried out on arthropods, fish, birds, rodents, carnivores and primates. Comparatively flexible behavior in humans, is seen as selected for by BE. Principles of optimality underpin BE, where individuals are always assumed to relate to their environment to maximize their reproductive success (Shennan 2002, 3). BE exponents are therefore particularly interested in examining links between ecology and adaptive behavior. BE is not tautological, as in terms of a given model, deviation in predicted behavior from the reproductively optimal may be identified. Perhaps counter-intuitively, many human behaviors apparently conform to these optimal predictions, reinforcing the view that despite the majority of humans are very sensitive to environmental cues which affect the probability of survival and reproductive success, and respond accordingly. How you determine which behaviours are optimal – or 'good enough', and how you determine which data reflect the 'true' picture, is problematic. However, there currently seems no better alternative than to take inclusive fitness as the OFT models' currency for actors in a given environment (Kelly 1995, 51; Shennan 2000, 4).

Several methodological issues relating to technology remain both characteristic and problematic to BE. In theoretical terms BE depends on the *phenotypic gambit*, which takes a 'black box' approach to precise mechanisms involved in genetic and cultural inheritance – much in the same way that Darwin could explain how species change independent of knowledge of precise cognitive, inheritance, and phylogenetic mechanisms involved (see above). BE in fact plays up the plasticity of the human phenotype at the expense of these precise inheritance mechanisms, in the hope that the end phenotypic result, the resultant technology in this case; remains unaffected (Smith 2000, 30). Models to explain adaptative behavior do not require cognitive, genetic, or phylogenetic components (Smith 2000, 30). Therefore three main conclusions can be drawn from BE, firstly contemporary socioeconomic environment is the causal mechanism for behavioral diversity, rather than behavior being affected significantly by past environments, cultural inheritance or contemporary variation in genes. Secondly, the precise mechanisms that give rise to adaptive behavior are unknown and unimportant. Finally, the plasticity of the human phenotype is highly rapid, and well adapted to most factors within contemporary environments (Smith, 2000). The timescale of BE is synchronous, and therefore well suited to ethnographic studies, where costs and benefits concerning specific currencies, e.g., protein obtained by individuals or their reproductive success can be relatively easily predicted and tested against optimal values or various evolutionary stable strategies (ESS). Technology is not treated separately from other aspects of human behavior, and is simply considered part of the synchronous adaptative response. Technological change occurs when the benefits – conscious or unconscious – outweigh the disadvantages in terms of fitness, a return to the 'necessity is the mother of all invention' argument (Fitzhugh 2001). As Shennan notes (2002, 1), BE does not see culture as feeding back into the crucial process of weighing up of short term fitness costs and benefits for the individual, as any behavior deviating from the predicted norm will be selected against over the long term. BE is therefore the most sociobiological evolutionary paradigm at present.

1.11 Evolutionary Archaeology and technology

Exponents of Evolutionary Archaeology (EA) follow Dunnell's (1978) polemical lead, which can be seen as a reaction to BE, and in many ways takes the opposite evolutionary approach to BE. EA stresses that mode, tempo, and scale of evolution have to be accounted for, following David Hull (see above), and sees human tools as part of the extended human phenotype. EA proposes that the genes controlling tool manufacture are subject to selection and drift processes, in the same way teeth, bones, bird's-nests and spider webs are affected by genetic processes in the animal kingdom. EA is particularly influenced by the way fossilized remains are viewed by palaeobiologists. A direct use of palaeobiological theory is therefore seen as appropriate – EA draws heavily on the work of Gould and Eldredge, who propose that historical contingency is all important for explaining lineages of biological species. Gould and Eldredge's (1977) idea of punctuated equilibrium (PE), where long periods of evolutionary stasis are punctuated by rapid speciation events within a single lineage of organisms, is demonstrated by fossil evidence of the Cambrian Explosion. PE is seen by EA exponents as potentially highly analogous to certain artifact trait changes, and subsequent artifact class changes, with a potentially recoverable archaeological signal, at different evolutionary scales and tempos (O'Brien and Lyman 2000). For instance, projectile points may not change for a long time but may undergo rapid changes in morphology due to the result of tiny cumulative trait changes and/or fluctuating selective environments – perhaps explaining why classes of 'Folsom' and 'Clovis' projectile points occur at the same time in the same locale (O'Brien 2000, 370).

For EA, differentiating between analogous and homologous technological lineages is all important if a 'Darwinian' explanation is to be achieved. Technology is studied at the trait level, rather than at the artifact unit level, so homologous transmission of tool-traits lineages can be established by utilizing theoretical units of analysis (see O'Brien et al. 2001). EA proposes that artifact traits do not possess *immanent* properties, properties which a thing possesses regardless where it exists in time and space (O'Brien and Lyman 2000). Instead, EA sees artifacts as *configurational* - comprising of characteristic traits that are instead dependant on their position in time and space, that exist in a materialist continuum (see Clark 1968/1978; O'Brien 2000, 399). Unit issues are everything in EA – a complex metaphysic is developed that shows a stark difference between the essentialist units (discrete kinds) used in physics and chemistry, and the materialist units (those that are continually becoming something else), that EA exponents propose should be used in historical sciences. This approach is developed from the work of some evolutionary biologists e.g., Ernst Mayr, who proposed that population, rather than typological thinking, is appropriate for the historical sciences (Mayr 1959, 412).

EA does not discount the role of human intent, but sees it as another source of generating phenotypic variation for sorting mechanisms to work on. The role of selection and historical contingency - phylogenetic history - are played up at the expense of behavioral plasticity and the synchronistic response of the human phenotype. Despite a wealth of challenging theoretical papers, the chief drawback with EA is the dearth of convincing case studies compared with BE. The difficulty in applying EA methods to archaeological cases is compounded by a theoretical preoccupation with complex units of analysis issues (O'Brien 2000), that are conveniently avoided by BE exponents, who employ the 'black box' approach of the phenotypic gambit (see above).

Confusing matters further, Dunnell drew a very sharp distinction between style and function in artifact traits in 1978; and this immutable definition has dogged EA ever since. Style is a word with many archaeological connotations. If Dunnell was more specific and used the term *drift* instead of style, there may have been less confusion amongst his critics. In EA, theoretical traits have to be tested as either functional or stylistic, to determine whether or not selection or drift processes are acting. Without an inductive reconstruction of archaeological context, i.e., the environmental constraints for a given technology, this is very difficult to do, as there is no *a priori* reason why the material correlates of selection processes should not resemble the material correlates of traits subject to stochastic drift processes. Another major problem with trait level analyses is determining pleiotropy (the phenotypic effect of a gene on more than one character) and polygeny (the phenotypic effect of multiple genes on one character), among cultural traits that could confuse interpretation of resultant technological lineages (O'Brien and Lyman 2000, 403). To rectify these issues, EA proposes careful use of analytical tools to tease these problems apart, chiefly the archaeological techniques of occurrence, frequency, and phyletic seriation. Cladistic theory and analysis is another methodology recently explored by EA, as this type of phylogenetic analysis classifies traits on the basis of their relationship to a common ancestor through shared derived characteristics (synapomorphies). Cladistic analyses are only recently possible due to the widespread availability of increased computing power (O'Brien et al 2001; see chapter three).

1.12 Dual Inheritance Theory and technology

Boyd and Richerson (1985) proposed a Dual Inheritance Theory (DIT) that in many ways runs closest to Darwin's original population/species level analysis in *Origin*. Culture and genes are seen as two separate but linked systems comprising Darwin's original pre-requisites for evolution, inheritance, variation, and fitness effects that result in evolutionary change (Smith 2000, 31). DIT in many ways cuts across the perspectives of BE and EA, as formal models are developed to test the more complex aspects of both approaches e.g., when style can be functional, and vice versa (Bettinger, Boyd, and Richerson 1996, 158).

Under a DIT paradigm, social learning through cultural transmission is seen as a key cultural evolutionary mechanism. Differential persistence of technological lineages is studied by formal mathematical modeling of traits acting in a population, which generates expectations that can be measured empirically. DIT exponents keep an open-minded approach to the influence various evolutionary forces may have upon differential persistence of cultural traits, which owes much to a methodological rooting in population genetics. DIT practitioners propose different cultural transmission pathways – such as non-parental learning (e.g., oblique as opposed to vertical learning pathways) can leave differential archaeologically recoverable signatures through indirectly biased transmission mechanisms (Boyd and Richerson 1985). For instance, trial and error learning can be differentiated from parent to offspring vertical modes of social learning, through differentiated ranges of continuous variables in separate lineages of projectile points. When disentangled, different traditions of projectile points can then be explained in terms of different social learning populations with separate technological histories (Bettinger and Eerkens 1999; see next chapter). Resultant traditions may even be maladaptive due to contingent social constraints, although these are thought to be mainly seen in more complex social hierarchies, such as those found in state level societies.

With DIT, evolutionary scale, mode, and units of analysis have to be very carefully qualified, and the cultural trait composition of the population studied must be carefully defined (Boyd and Richerson 2000, 154). This preoccupation with complex formalized detail has limited the numbers of DIT case studies in the same way that complex unit definitions have limited EA case studies. In contrast to EA, it is the individual that DIT takes as the decisive unit of analysis – so by modeling demographic history of populations with or without a technological trait, the action of different evolutionary processes affecting trait transmission may be hypothesized and tested (Boyd and Richerson 2000, 161). DIT case studies are beginning to appear in the archaeological literature, whilst technological studies at the population level could be further illuminated by the DIT approach when tighter chronological control and populations can be better hypothesized; this remains largely an empirical issue (Bettinger and Eerkens 1999, Shennan 2000, 2002; Henrich 2004; see chapter six).

Fluctuating populations have been seen as causal to innovation processes by Fitzhugh (2001), who noted populations under resource stress have more reason to innovate new technological adaptations than stable populations; the former have less to lose by adopting riskier behaviour. Henrich (2004) used formal modeling and qualitative Tasmanian data to propose that a sudden drop in the effective population at the end of the last Ice Age was responsible for the loss of certain complex skills and technologies, and a probable increase in the complexity of relatively simple skills (Henrich 2004, 204). The process of imperfect copying of different social models was seen to play a key role in technological change, and cumulative cultural evolution was seen to be dependent on larger pools of interacting social learners. In Tasmania, this combination of differential cultural transmission rates appeared to have accounted for the loss of complex fishing technology, and the simultaneous increase in less complex stone tool technology, shown in the archaeological record (2004, 209). The size of an interacting pool of social learners was formally modeled, and found to be positively correlated with adaptive evolution; the larger the population of interacting social learners, the more likely it is that selection will favor an adaptive process, resulting in a faster tempo of cultural evolution (Henrich 2004, 202). Maladaptive loss was seen to be more likely if a complex skill, rather than a simple skill, was copied in a small population, rather than in a large population of interacting social learners. Technological changes in Tasmania were then causally linked to early Holocene climate changes, which effectively isolated the populations on Tasmania, and circumscribed their selective transmission choices (Henrich 2004, 197). One major criticism of Henrich's work is that, despite presenting a method with great explanatory potential, his empirical data set was not analyzed in a quantitative manner; this is a problem that will be addressed by the case-study in this thesis.

It follows that relatively complicated technology such as the bow-arrow, as opposed to simpler technology such as the thrown spear (see Hughes 1998), would be less likely to be innovated when people were in relatively small dispersed stable populations, as long as existing strategies of prey-capture proved adequate. In other words, alternative prey capture adaptations may prove just as effective as the bow, as it would be to risky to innovate or copy a new technological tradition, especially in a fluctuating and unpredictable environment. It follows that a new tradition would be more likely to develop and persist in a population of interacting social learners, when the effective population is higher, and the environment is less variable. However, it would seem reasonable that at the weapon-system level, given enough competing technological variants in a given social-learning population, bow technology would eventually be favoured by selection, as it has a functional edge on other early projectile systems (Hughes 1998). It is reasonable to assume that certain archaeologically recoverable technological aspects within a weapon system, such as lithic arrow head morphology, should reflect these cultural transmission biases, if the effects of other formation processes, such as lithic re-sharpening, can be accounted for (see Bettinger and Eerkens 1999).

These analytical perspectives fit well with Flannery's Broad Spectrum Revolution (BSR) theory (Flannery 1969), recently championed by Stiner (2000). BSR theory sees a positive feedback effect between the widening of diet breadth and related increased numbers of humans, archaeologically visible from the Middle Palaeolithic (MP) to Upper Palaeolithic (UP). Stiner's faunal studies of small prey in Mediterranean regions show slow moving species sensitive to predation, such as tortoises, characterised 52% of her MP faunal assemblages. Faster moving game such as hare characterised later UP assemblages. One of a series of innovations and prey-capture strategies facilitating the capture of UP fast moving prey would be the bow-arrow, although the antiquity of any supporting technological evidence makes it difficult to empirically demonstrate as there is no necessity for stone tipped points - fire-harden/blunt tipped wooden arrows can be equally effective on small game (Ellis 1997). Clark noted the use of microliths may have been used for arrowheads in sub-Saharan Africa up to 50,000 BP (Clark 1974, 323). The conceptual leap from a UP bow-drill for fire production or bow-trap for snaring game, to a bow-arrow projectile system is not so great – as Alfred Kroeber proposed last century (Kroeber 1948). Precise geographic origins of the bow may never be known given the paucity of early evidence, however, much can be learnt from a detailed case study of archery technology in a more detailed environmental context than previously attempted.

1.13 Summary of thesis

This section will summarise the remainder of the thesis, chapter by chapter.

Chapter two specifically considers bow-arrow technology from an evolutionary perspective. Key evolutionary mechanisms are related to drift, selection and population driven social learning mechanisms discussed in the previous chapter. Old World traditions for studying bow-arrow technology are reviewed, prior to a comparative analysis of New World traditions. The former are shown to be initially preoccupied with inductive classification issues, prior to developing simplistic invasion and diffusion hypotheses (Clark 1974). Primarily, these approaches are seen to conflate scales, mode and tempo of evolutionary analysis (see O'Brien and Lyman 2000). With an associated misappropriation of contemporaneous evolutionary theory, transatlantic scholars have proposed notions of linear technological progress (Carneiro 1970). New World studies are again found to be initially typologically concerned, linking 'origin-debates' and specific lithic technologies to the 'First Americans'. Later debate centres on locating first bow-arrow users as opposed to atlatl/spear users – and the extent to which these technologies overlap temporally (Hughes 1998). 'Middle range theory', linking meta-theory with data is essential to tease apart competing hypotheses (Bettinger et al. 1996). Typological and quantitative classification techniques were developed in parallel to the Old World methods. Functional and experimental approaches from both sides of the Atlantic have preceded various evolutionary approaches towards technological issues. Different evolutionary 'schools' from recent times are shown to be themselves historically contingent, but not necessarily mutually exclusive. Culture historical paradigms are therefore reassessed in light of findings from chapter one. Methods relating projectile point types to specific groups of people are considered heuristically acceptable given specific preconditions, but finer levels of analysis find such essentialist thinking to be often logically flawed or lacking explanatory power. The use and misuse of frequency seriation techniques are given as an example. An alternative holistic method identifying key evolutionary processes utilising population models in conjunction with fine grained archaeological and environmental case study data is presented.

Chapter three is an introduction and overview to the Mesolithic south Scandinavian case study data. Specific geological, climatic, environmental, population and technological considerations are reviewed. Extant paradigms for early Holocene prehistory in the region are summarised, and previous approaches towards subsistence technology and culture change are divided into four broad theoretical categories with a summary of associated units of analysis. These include the prevailing culture historical paradigm using seriation and typology (Brinch Petersen 1973; Vang Petersen 1984), ecological approaches using environmental and osteological settlement occupation evidence (Larsson 1982; Rowley-Conwy 1983; Karsten and Knarrström 2003), economic models (Blankholm 1994; Price 1991), and functional approaches using experimentation and use-ware analysis (Fischer 1984, 1988; Friss-Hansen 1990; Knarrström 1991). The sites, phases, and data used for the case study are then detailed. Nine site phases from the Atlantic pollen zone period comprise the case study. They contain cultural divisions traditionally termed Blak, Kongemose and Early Ertebølle. These phases contain various amounts of conventional radiometric data, lithic and lithic projectile point data, osteological and ecological data. Each site is discussed in terms of amount and quality of data relevant for constructing appropriate evolutionary units and models detailed by the two previous chapters.

Chapter four presents a Bayesian chronological method specifically tailored for the evolutionary study of the case-study armatures. Problems with Scandinavian Mesolithic chronology are detailed. Relative typological approaches are deemed potentially circular, reliant on seriation techniques that may not be able to satisfy certain theoretical prerequisites. Use of absolute dating methods is then discussed. A summary of pollen analysis phase dating is given. The case-study radiometric data are considered - problems with current interpretation of conventional ^{14}C data are highlighted on a phase by phase basis. A theoretically desirable Bayesian phase model is presented and explained. The model classifies case-study point-bearing phases in terms of known radiometric data, archaeological boundary data, and vagaries of the calibration curve. This is accomplished using statistical modelling features of the OxCal calibration package, that calculates probability distributions of specified events happening, in calibrated calendar years. Being independent of typology, this chronological method allows start and end boundary probability distributions of each point bearing phase to be compared with others solely in terms of all available radiometric data, and the known stratigraphic archaeological data. The results are presented sequentially and graphically, with probability distributions calculated for each phase boundary start, phase boundary end, and phase duration. In addition to the tables, models, and graphs displayed in illustrations section, all OxCal model data and associated radiometric data are stored on files contained in the Appendix CD.

Chapter five is a summary and analysis of the time stepped armature data set. Previous analytical approaches towards armatures are detailed concerning experimental, ethnographic, use-ware, and statistical techniques used to distinguish microliths from projectile point armatures and specifically arrow points. Reasons for concentrating on continuous point variables instead of qualitative properties are explained in terms of case-study specific engineering constraints, lithic raw materials, and associated lithic reduction strategies. These approaches are summarised into a series of trait-distribution expectations relating to known engineering constraints for certain lithic arrow heads. An alternative holistic method using independent lines of evidence is proposed to determine whether trait distributions are due to selection and adaptively functional, or subject to stochastic drift, in terms of analytically compatible faunal and environmental data. Trait variables and metric data obtained from the points used in the quantitative analysis are then qualitatively summarised. The point data sampling strategy is explained in terms of standardising uneven numbers of points distributed across phases for consistent, meaningful, comparison of other phase data. The chapter then accounts for intra- and inter-site morphological armature variation by using a linked series of statistical techniques, which result in a middle range theoretical level of explanation. In general, the statistical method used removes a site a time from each statistical analysis, allowing trait patterns to be more easily recognised and graphically represented. Descriptive statistics summarise the distribution curves of all point trait variables for each phase. Bimodal frequency distributions are hypothesised to represent different reduction strategies. The coefficient of variation is then used to summarise and compare the amount of variation for each point trait from each phase. The results are displayed in both graphical and tabular form. Discriminant analysis is used to classify each point in terms of its own assemblage and other assemblage, to determine strength of predicted relationship with its own known phase assemblage - and its relationship to all the others. A principal components analysis is then run, as a final exploratory multivariate technique. This describes this relationship and the degree of variation between all point trait variables, across all phases. Finally, to summarise the point data as succinctly as possible, scattergrams using confidence ellipses are plotted, using the two point trait variables deemed to contain the greatest amount of characteristic variation for the phases, as distilled from the above analyses. A simple graph is then produced that displays the mean amount of variation, defining each of the nine point assemblages in a time stepped order. The implication of all results are then summarised. Resultant figures and tables mentioned in the text are shown in illustrations section, whilst all data and models used are also held in SPSS and Excel files in the attached Appendix CD.

Chapter six places the summarised time-stepped point data in contemporaneous environmental and population level context. A series of models are formulated to explain armature point variation in terms of trait variation and trait stability. A faunal analysis of four published point-bearing phases representative of the entire case-study chronological span is used. This investigates possible functional relationships between potential prey-species, potential diet breadth, and summarised projectile point variation. Published NISP and species data from the Segebro and Tågerup phases is initially modelled using both NISP proportion pie charts, and the NISP/NTAXA relationship as hypothesised by Grayson and Delpech (1998). At the phase level scale used, no relationship is found between prey type and point shape.

A demographic model is then constructed using the OxCal calibration package. This method expands on that presented by Gkiasta et al. (2003), where the sum of all known radiometric data is entered into a model that averages the result into a fluctuating probability distribution, plotted over calibrated calendar years. A further analysis averages each known date from an occupation phase into a single probability value representative of the phase. All average dates are then summed. This method accounts for sites that have a disproportionate amount of radiometric data. The results are shown in calibrated calendar years and shows hypothetical population fluctuations that span the final Maglemose to the end of the Ertebølle cultural phases.

Environmental causes for the hypothesised population fluctuations are then examined. Sea level rises and landmass reduction are plotted for the south Scandinavia case study area against the estimated relative numbers of humans and ungulate population densities. This data was calculated using the biotic information calculated recently for the Mesolithic environment of Great Britain for c. 7000 BP, and by simply reducing these figures by 5% each time step (see Maroo and Yalden 2000). The results show that even if contemporaneous human population densities were extremely high, the relative biomass of ungulates could be still be sufficient to sustain proportional prey-capture rates, regardless of the rest of the mammalian biomass. Consequently, relatively rapid land mass reduction is not seen to cause populations to leave the case study area, especially as new environments created by isostactic and eustatic processes would have been even more productive, in terms of new estuaries and marshes being created, with a different range of associated prey types.

As land mass reduction was not considered to be the causal mechanism affecting population fluctuation, the pollen statistics data were qualitatively examined. There was no sign of deforestation, that may have affected the human food chain significantly in the case study region, through the temporal period of the study.

A climatic hypothesis is presented to explain population fluctuation (Gamble et al. 2004). A final environmental model using proxy climatic data juxtaposes Holocene isotope ration $\delta^{18}O$ data with $\Delta^{14}C$ data, which is used to plot climatic fluctuations and temperature changes. Differential populations are related to fluctuating resources affected by a changing climate. In the final analysis, environmental change is seen to be broadly correlated with the proposed population fluctuations, and specific changes to lithic arrowhead technology.

Chapter seven draws together theoretical conclusions and case study results of the previous chapters. Changes in lithic reduction strategies and mean point shape variation are shown to correlate with population fluctuations and climate change. Technological change in the case study is explained by a causal mechanism of climate change linked to population fluctuations. These are shown to affect different social learning strategies which then constrain technological transmission pathways of evolutionary traits, through a stochastic drift mechanism. The implications of this study are then discussed in relation to existing theoretical approaches, and potential future research.

Chapter 2: Evolution of bow-arrow technology

2.1 Introduction to bow-arrow technology

This chapter looks at previous approaches to bow-arrow technology, explains taxonomic definitions, and develops an appropriate case study method in terms of recent evolutionary theory and available empirical evidence.

This section is an overview of technological issues concerning bow-arrow technology, the next section is an explanation of essential terminology and general taxonomy used to describe aspects of the weapon system. Examples of different multi-linear developmental trajectories of bow-technology are then presented. This is prior to a comparative history of New and Old World academic approaches to archery. The chapter concludes by synthesising appropriate methodology for an evolutionary archaeological case study.

Despite widespread recognition of pan-historical importance for bow technology in subsistence and warfare in non-state societies, surprisingly little research has been undertaken on this specific system other than the anecdotal. The precise role of bow-arrow technology in prehistory remains enigmatic. That is not to say interesting, controversial questions surrounding prehistoric and historic archery tackle remain unaddressed. Indeed, arrow-point typologies form the backbone of relative dating techniques in many parts of the world, not least for Mesolithic Scandinavia (Brinch Petersen 1973; Vang Petersen 1984; Beck 2001; see below). The problem is that questions and theoretical units of analysis are not synchronised at a scale to be informative in terms of recently developed evolutionary theory, despite large amounts of available empirical evidence (O'Brien and Lyman 2000). Studies have focussed on artefacts, usually relating to narrow inductive social-historical questions, rather than theoretical traits and their wider evolutionary implications. It is argued below that the latter is the scale of argument where projectile technology, particularly bow-arrow technology is most productively analysed.

Few studies refer to the effect bow-arrow technology had on populations in terms of impacting prehistoric demography and diet breadth, increased or decreased rates of inter/intra group conflict, or wider environmental impact in terms of unsustainable resource acquisition rates (except Petrequin 1993; Maschner and Reedy-Maschner 1998; see below).

The case study presented in the following three chapters will address these issues. Although lithic projectile points are prolifically used as temporal diagnostics linking presumed culture historical affinities (Brinch Petersen 1973; Vang Petersen 1984), evolutionary developmental trajectory of projectile technologies - archery in particular - remain largely unquestioned and teleological. Associated research remains empirically driven rather than theoretically framed (Fischer 1988). A recent edition of *American Antiquity* focused upon these issues with mixed results (Nassaney and Pyle 1999; Bettinger and Eerkens 1999; Morrow and Morrow 1999; see below).

Experimental studies of bow-arrow technology have traditionally been made in parallel with other different projectile weapon systems, such as spear and spear thrower (Atlatl), to establish developmental ordering for relative dating purposes (Knecht 1997; Hughes 1998), or relative functional performance (Miller 1986; Fischer 1988; Bergman 1993). Although experimental studies provide a wealth of functional performance information, it is argued that contextualising ecological information is required to link middle range studies of this order to meta-theory of evolution (Shennan 2000).

Recently, Bettinger and Eerkens (1999) used Boyd and Richerson's (1985) social learning theory to distinguish between two lineages of lithic arrow-head manufacturing traditions by focusing on differential sets of continuous variables. Projectile neck width/weight variables correlated in one tradition but did not in another, the proposal of different social learning mechanisms resolved a longstanding typological dispute in the American Great Basin. Bettinger and Eerkens' method of linking empirical data, middle range studies, and population level evolutionary theory has great potential.

The remainder of this chapter will focus on explaining technical terminology, on giving examples of underestimated complexity of bow-arrow developmental trajectories, and the synthesizing of previous academic approaches to bow-arrow technology, in terms of contextualising the case study methodology.

2.2 Bow-arrow systems

Mechanically, the bow is a two armed spring placed under tension by a string (see **fig. 2.1**). When drawn, the bow stores potential energy, upon release the energy is transmitted to the arrow which is then propelled into flight (Bergman 1993, 96). Bows are usually divided into three broad technological categories for convenience by bowyers, archers, and archaeologists. These are the self-bow, the sinew reinforced bow, and composite bow. Experimental evidence suggest that these broad weapon system-categories have significantly different manufacturing traditions and performance characteristics (see **fig. 2.2**; Bergman et al. 1988). Although bow-arrow systems can be ecologically circumscribed due to lack of certain raw materials, there is no evidence to suggest a single point of origin and simple diffusion mechanism of bow technology - various complexities of bows appear in counter-intuitive orders in different places in the archaeological record. Intuitively, its seems reasonable to assume that bow-arrow technology is easily copied and horizontally transmitted between populations, however, this assumption requires careful qualification, on a case by case basis. Due to the length of time required to learn to make and effectively use bow systems in traditional contexts (see below, and previous chapter), each archery tradition should be seen in its particular historical and ecological context, whilst any loss and innovation is proposed to be closely correlated with the specific population history of a utilising group.

Bows and arrows are complex artefacts requiring explanation in terms of temporal and geographic distributions, nomenclature, taxonomic units and the extant empirical data. The following sections will put the narrow geographical remit of the case study into a wider context of multiple technological traditions.

2.3 Self bow technology

The self, 'simple', or long bow usually consists of a single wooden staff, and can be short as 1m or less used by the Kalahari San, or as long as 2m, as used by the Yąnomamö (Wiessner 1983; Chagnon 1997/1963). The European longbow is the earliest bow found in the archaeological record, and probably dates from the European Upper Palaeolithic if correctly relatively dated cave paintings are to be believed, although these dates are often disputed (Clark 1963, 80). It must be stressed that a lack of directly dated supporting organic evidence makes this claim difficult to verify (Clark 1963). Early extant examples can have long carefully shaped limbs up to 1.8m, usually with shaped handle-grips (Bergman 1993, 96) and pine examples (see below) were dated to the Late Palaeolithic of Schleswig-Holstein in northern Germany/southern Denmark by Rust (1943). Two examples of narrow grained elm bows (*Ulmus glabra*) from the Early Mesolithic Holmegaard level IV c. 6000 BC, were excavated on the Danish island of Zealand by Becker (Becker 1945; Rausing 1967, 49). Lars Larsson found two Atlantic period long bows made of European mountain ash or Rowan (*Sorbus aucuparia*) in the Swedish site Ageröd V, dating to 6860-6540 BP. One was c. 36 years old when cut down and made of narrow grained elm (*Ulmus sp.*) carefully constructed with a 'D' shaped cross section characteristic of complex long bow technology, whilst the other was more oval and less complex – indicating possible expedient manufacture, or two separate traditions (Larsson 1983, 57; Bergman 1993, 98). The later Ertebølle period from Tybrind Vig yielded two complex 'D' shaped Elm *Ulmus* bows (Andersen 1985, 61). Although rare, a total of five carefully designed longbows were found alongside several others of considerably less complexity in the Scandinavian Mesolithic (Bergman 1993, 98), indicating a great antiquity of associated manufacturing technology, and at least two separate bow 'product histories'. Great subtlety is shown in the earliest bow construction, notably in choice of wood, and particularly in the shaping of limbs grips and nock ends (where the string is attached to the bow). The two roughly contemporaneous Neolithic bows found at Ashcott and Meare Heath in Somerset peat deposits in 1961 also displayed distinctive morphological variation, indicating different technological lineages. The Ashcott bow has a rounded cross-section and was comparatively inefficient, whilst the Meare bow is very wide and thin and reinforced with binding, and mechanically closer to an optimum design following the results of Klopsteg's experimental work (1943;1947). Despite similar radiometric dates of 2665 +-120 and 2690+-120 respectively these bows appear to represent different manufacturing traditions (Clark 1963, 56, 65-67). The single stave long bows similar to Holmegaard IV bows in the National Museum of Denmark are thought to be the type weapon of the European Mesolithic, although only a handful have been excavated (Rozoy 1989). In terms of performance relating to the choice of materials it has been demonstrated by experimental replication studies that flat-backed Mesolithic bows are equal to the English medieval long bow. Bow-staves from both periods were apparently made of an efficient combination of sapwood and hardwood, whilst the long bows recovered from the Mary Rose have a flattened sapwood back (Hardy 1976). Bergman supposes that the inferior performance of replica narrow limbed English long bows compared to the wider limbed flat back bows of the Mesolithic was perhaps to maximise the raw materials (Bergman 1991, 79). However there is no *a priori* reason to assume that the English had better technical knowledge.

Performance characteristics of the English long bow are often underestimated, as demonstrated by reconstructions. They can require maximum string pull-weights of 100-175 pounds pressure, and the use of a protective arm bracer, which may have archaeological correlates that remain unidentified (Clark 1963, 77; Edinborough 1999, 18-19). 172 extant examples were salvaged from the Mary Rose, Henry VIII's flagship, ignobly swamped and sunk July 1545 sailing from Portsmouth to engage the French fleet, and contemporary to Roger Ascham's (1545) pioneering book of archery, gifted to Henry the same year. These longbows were very similar to those famously used at Agincourt in 1415 (Hardy 1976). Almost all the Mary Rose bows were made of Yew (*Taxus baccata*) that possessed the most consistently compressive heartwood and tensile sapwood, probably imported from Spain. The accompanying arrow shafts were mainly poplar *Poplus*, although Ascham reported ash was far superior (Ascham 1545, 120; Hardy 1976, 185; Bradbury 1998, 155). These longbows require complex manufacturing knowledge, and for optimum mechanical performance require up to three years of flexing and air drying, ideally whilst braced on a 'tiller' rack (Hardy 1976, 187). Ethnographic evidence shows a Yąnomamö self bow can propel a six foot arrow through the body of an opponent at 'considerable' ranges (Chagnon 1997, 51, 193, 200); but such a powerful cast is gained at the expense of unwieldy length, required to prevent the stave from breaking.

The early empirical evidence of the longbow - if lithic technologies are ignored - would suggest a northern European origin with a temperate climate. However this may be an accident of artefact survival; organic remains are not generally preserved in the arid conditions of the Near East, in contrast to those in northern European wet sites. Bradbury declares the long-bow evolves from the ordinary wooden bow over a long period (Bradbury 1985, 15); however due to paucity of contextualised bow staffs, it is difficult to speculate as to origins and transmission mechanism for this type of bow. Better preserved lithic arrow head technology may provide a better indication (see below).

2.4 The composite bow

Composite bows are usually divided into at least three sub-categories, the reinforced bow, the true composite bow, and the Japanese bow, although Bergman lists four (1991, 80). The reinforced bow is usually a one piece staff strengthened by an added laminate of sinew and/or bark glued to the back, or by carefully placed binding (Rausing 1967, 19).

Ethnographically, Inuit groups bind on bow reinforcement while other groups usually use fish or animal glues (Rausing 1967, 19). Reinforcement allows a faster shot with a longer draw and cast, by preventing the wood from snapping and increasing the tensile elasticity of the bow (Cattelain 1997, 221). This bow can be significantly shorter than the self bow without dramatic loss of power - it is often half or three quarters the length (Bergman and McEwan 1997, 145). An early European example is the Meare bow, with criss-cross bindings, found in a phase of the British Neolithic Somerset (Clark 1963, 54-55). Composite and reinforced bows are usually 'reflexed' when unstrung - the two limbs 'recurve' back on themselves the opposite direction to that when strung. This preloads the bow with more power than a self bow (see **fig. 2.3;** Bergman and Miller 1997, 145).

Cattelain suggests that the earliest pine heartwood bows c.11,000 BP found at Stellmoor by Rust may have been sinew reinforced as pine is comparatively brittle, and poorly suited to long bow construction (Beckhoff 1968; Cattelain 1997, 220). These may have been made expediently from elastic unseasoned wood, or may have been examples of an inefficient manufacturing tradition. Ethnographically, reinforced bows are common to the indigenous peoples of North America. This is the bow often used by North West Coast groups, initially introduced around 500 AD (Ames and Maschner 1999, 200). They can take only a few days to manufacture as observation of indigenous peoples have demonstrated (Pope 1918, 112). However, there is no inherent reason why this bow should not be found elsewhere and very early in prehistory, as the Meare example demonstrates. It could have been discovered by populations in various locales and periods, perhaps by an effective binding of a broken self-bow staff. Broad scale evidence suggest that these bows can develop from a single point of diffusion, but finer grained lithic studies in the same location can show independent horizons of innovation - this is a current issue in American archaeology. Morrow and Morrow (1999) postulate a broadly linear diffusion of projectile technology from north to south in the Americas using points found in association with radiometric data, whilst Bettinger and Eerkens (1999) postulate a wider diffusion horizon, but with unique local innovation/copying histories for the (probably reinforced) bow-arrow in the Great Basin, in terms of different populations competing for the same resources.

The 'true' composite bow is a highly complex weapon, with multiple component parts - wood, bone, horn, sinew, glues and bindings, with a complicated laminated construction sequence

(Bergman and Miller 1997, 159). It has a great antiquity, dating to Bronze Age Eurasian steppe nomads, and can be seen co-occurring with evidence of horse domestication (Shishlina 1997). Elsewhere it can be seen developing with chariot technology in early Mesopotamian states (see below; Moorey 1986). These bows are very short, roughly the same size as the reinforced bow but much more recurved, requiring considerable skill just to string the bow. Composite bows allow a draw well past the ear, storing considerably more potential energy than the other two bow classes. It requires more training due to deeper draw length, greater draw weight, and comparative complexity of release-grip usually required for optimal release (see **fig. 2.4**) Payne-Galloway 1907; Klopsteg 1947, 3). These bows typically take a year to be dried, cured, and ready for use, which compares surprisingly favourably to the European longbow, which takes up to three. Sensitive to cold and damp conditions, composite bow technology seems circumscribed to drier climates, which may explain the ethnographic prevalence of the 'thumb-grip release' to the Near and Far East (Kroeber 1923).

Characteristically these bows have a string pull weight of around 60 pounds, considerably less than a longbow, which can require three times this. Because of the extended draw length allowed due to increased mechanical efficiency, complex bows can be half again as powerful as a self bow of the same length (Rausing 1967, 147). This disproves Balfour, Pitt-Rivers, and Clark's assumption of no inherent technological advantage in the composite bow (Clark 1963; Balfour 1890; Pitt Rivers 1877). Although functionally superior to most 18th century firearms in terms of rate of fire and accurate cast of projectile, this weapon required no metallurgical knowledge or components (Klopsteg 1947). The Japanese composite bow is a longer limbed variation on the Asiatic composite bow and because of good historical evidence, provides an excellent case-study for multi-linear bow technologies (see below).

2.5 Arrows and lithic arrowheads

Traditionally, arrows are usually made by the bow user, and can be very simple or complicated, depending upon local traditions, and expediency of the shooting situation. More than 100 Late Glacial pine arrows were recovered from an Ahrensburgian level at Stellmoor, Schleiswig Holstein by Rust (1943) dated to the Younger Dryas c.9000-8300; many fore-shafts retained their oblique microlithic points; however although the associated osteological evidence survived the ravages of World War II, apparently no arrow shafts that have hafted microliths survive. However, a complete stone tipped arrow was recovered from Lilla Loshult in Scania Sweden and dated to the Early Boreal, 7000 BC (see **fig. 2.5A;** Petersen 1951; Clark 1975). More examples of complete early arrowheads with transversely mounted trapezoid heads have been found in Denmark and Germany (Brøndsted 1957; Troels-Smith 1959; Clark 1963, 95-97; Bergman 1993, 99-101). Possible early examples of barbed and tanged arrows, assuming no problems with radiometric dating and stratigraphy, are dated to 18,500 BP in the Parpelló cave, Spain by Péricot-Garcia (Péricot-Garcia 1942, fig 21; Clark 1963, 61; Gamble 1986, 263). Although attributed to Late Solutrean deposits underlying Early Magdalenian deposits, on qualitative grounds they look like later Neolithic or Bronze Age heads found elsewhere in Europe. Considering the 1942 publication and nationalistic atmosphere in Franco's Spain, despite wartime neutrality, a re-examination of these arrowheads and the dating surrounding their stratigraphic context, may be wise. When compared to the early but more securely dated composite bone and lithic bladelet projectile point from the 13th millennium BP found near a hearth in the Magdalenian site of Pincevent in the Paris Basin (Leroi-Gourhan 1983), the complex bifacial technology of Péricot-Garcia's example looks implausible (but not impossible), on relative dating grounds. Clark tactfully notes these early bifaces look like arrows but may instead be dart points (1963, 61), whilst there is no *a priori* reason why Péricot-Garcia's examples are not arrowheads.

Arrows, as opposed to atlatl propelled thrown darts, require an arrow nock - a slot or split at the distal end of the arrow to comfortably rest on the bow string allowing release without a dangerous slip (see **fig. 2.5B**). A nock is considered universally diagnostic of an arrow archaeologically (Pope 1962). All other technological aspects of an arrow may be variable and there is no technological necessity for a stone tipped point (Diamant 1977, 385). If poison is to be used, bows can be simple and short (Clark 1974); there is no need to add a stone tip as organic compounds tend to stick better to wood or a fire hardened wooden tip, as demonstrated by the Hadza group's arrows (Bartram 1997, 333). Certain prey-capture strategies ideally require specific armatures; however, many examples of expedient use of the 'wrong' arrow have been ethnographically recorded (Ellis 1997). Although barbed and tanged arrow heads have been demonstrated to be specifically designed for warfare, to inflict the worst wounds (Keeley 1996, 52), such arrows can be quite basic. There is no obvious performance advantage in over-engineering an arrow design. Indeed, it seems likely from experimentation that as long as the lithic arrow head was considered 'good enough', many metric dimensions could vary (Fischer 1988). However, a group's social learning traditions and acceptable technological norms can place considerable constraints on point shapes, whilst selection (see previous chapter) may be still be significant at the continuous variable trait level.

In Northern European archaeological contexts poisons such as mistletoe may have been used on the fore-shafts of stone tipped arrows; weakened prey could then be tracked with dogs. However, no residue analysis has been performed in this context (cf. Clark 1974). A bamboo tip is highly effective, leaving splinters that often cause lethal infection (Chagnon 1997, 49). Bone tips are similarly very effective - this is a relatively easier material to work, and is ethnographically usually used for barbed fish harpoon tips, although bone tipped arrows, as opposed to spears, are not unheard of (Ames and Maschner 1999, 93-97).

It is worth noting that it is unlikely that all lithic bifaces and microliths diagnosed by archaeologists as arrowheads, are actually correctly identified as such. This is an important point that is addressed in detail in chapter five, but in the meantime without a diagnostic knock-end – the groove where the string fits an arrow – what is supposedly a complete arrow could conceivably be a dart (Shott 1997). Correspondingly, even more caution is required when attempting to differentiate between just the lithic residue of a projectile tip. However, with practical experiments, comparative macro- and microscopic use-ware studies (Fischer 1988), and carefully evaluated morphological evidence derived from statistically significant assemblages of known projectile tip classes (Thomas 1978; Shott 1997), much supporting evidence can be gathered to enable a convincing differentiation between different lithic armature classes.

Stone tipped arrows are universally considered by Ellis to be used for hunting large game - or humans - following evaluation of cross-cultural ethnographic evidence (Ellis 1997, 63). Pierre Pétrequin (1990, 1993) showed that recent New Guinea peoples, notably the Dani, also distinguish between simple points for killing game, and complex stone points for killing humans, that took much longer to manufacture. Like the Wintu and Nevada Shoshonean groups in North America (Keeley 1996, 53), the Dani poisoned war points to increase risk of fatal infection, the former with septic or toxic poisons, the latter with mud and grease. Pragmatically, these peoples still used war-points for game (Pétrequin 1990, 48, 50, 59), although no nutritional advantage could be gained from shooting 'septic' poisons into food, as pointed out by Keeley (1996, 52), as opposed to 'toxic' poisons as used by Yąnomamö (curare plant resin, Chagnon 1997, 51, 181) and the Kung San's *Diamphidia sp.* larval poison, used for war and hunt alike (Bartram 1997, 337). In a rather gruesome experiment, Clark tested two 4000 year old bone points from tombs in Nasa-ed-Der, extracting a black resin suspected to be poisonous, which he had injected into two mice - which promptly exhibited temporary symptoms of curare-type poisoning. Stronger poison collected from 150 year old San arrows sadly proved fatal to another mouse (Clark 1974, 242). Most archaeological arrowheads remain untested for toxins, which may have been in perishable bindings or organic fore-shafts as ethnographic examples often are; however, any distinction between septic as opposed to toxic compounds could indicate war-points. Clark noted in 1974 that it was very difficult to identify telltale cardiac glycosides - toxic poison - using a mass spectrometer with small amounts of test substances; however, more recent technological advances may now prove more useful (and certainly more humane) than his experimental alternative.

Much experimental evidence exists as to the most effective shape of stone arrow heads, as they are often the only surviving evidence of prehistoric archery (see below, Hughes 1998). Friss Hansen's experiments demonstrate that the ideal ratio between shaft diameter and maximum cross-sectional diameter of its arrow head was just over 1:1, this would cause the most tissue damage, blood loss, and maximise the likelihood of a single shot kill (1990). Whether a single shot kill is essential is debatable, and dependent on hunting strategy. Given evidence of early cave paintings where a coordinated group-ambush nature of bow hunting and warfare is apparently indicated (Keeley 1996, 45, n. 8), and the number of mass kill sites identified archaeologically such as Stellmoor (Rust 1943), it seems the most memorable bow-hunting events were likely to be the group-ambush of migratory ungulates, probably finally dispatched by hand-held weapons or harried by dogs. Paintings from the *Cueva de la Arãna* in Valencia Eastern Spain depict figures clearly holding long arrows apparently with large tips, the shafts only slightly shorter than the curved longbow staves (Clark 1963, 80). Without knowledge of usage, six foot Yąnomamö arrows are often mistaken for spears (Chagnon 1997, 51; and for rock art examples of very long arrows, see Beltran 1982, 44-45), whilst experimental work demonstrates that large 'Folsom' points can make very effective arrows (Browne 1938), so one must be careful not to assume large stone tips were only attached to spears.

2.6 Multiple lineages of bow technology

Prehistoric longbow technology is difficult to use as an example of multi-linear evolution as most early organic evidence has perished, and it is significantly less complex than other bow traditions

– undoubtedly it could be more easily imitated than its composite counterparts. However, it will be shown that experimental studies and 'product histories' suggest longbows are more intricate than assumed and may have multiple technological innovation and diffusion histories – the less complex self-bow has more chance of accidental technological convergence than more complex bows. Significantly, Roger Ascham noted that only through practise, instruction, and friendly competition in peacetime, would English archers ever become formidable in war - not through inherent technological superiority (1545, 82). At a state level, these social learning traditions were deliberately encouraged by Henry VIII's laws of 1511-12, which enforced minimum standards of archery skill throughout the adult population (Ascham 1545, ix). It follows that bow technologies are not inevitably 'progressing' - they are also subject to population drift effects where loss of effective learning populations precipitate loss of technologies, just as canoe technology and electric car technologies were lost (see last chapter).

The bow failed to occur indigenously in Tasmania or Australia and most of Polynesia; it is not inevitable (Cattelain 1997, 220), and this hints at geographical circumscription of complex knowledge – conceivably effective social-learning populations with bow technology bottlenecked and never arrived. Perhaps indigenous populations had other projectile adaptations, equally effective given area-specific prey-behaviour and hunting strategies (see below). Alternatively, the bow never took off in parts of Oceania due to chance lack of innovation – maybe indigenous peoples rarely used bow-drills either, further reducing the chance of innovation. It would be more surprising if a particular complex non-state weapon technology was omnipresent.

2.7 Multi-linear development of composite bow technology

Bergman and McEwan hypothesised composite bow technology may have developed during the third or second millennium BC, whilst Rausing demonstrates it can be found in Neolithic contexts geographically circumscribed towards the East (see **fig. 2.3;** Bergman and McEwan 1997, 144-7; Rausing 1967, 146). Direct evidence of bows and associated tackle apparently emerges around 3000-2500 BC in the Eurasian Steppe of the former Soviet Republic, notably with composite wooden core bow staves with horned plates, attributed to the Siberian Serovo culture, in the Lake Bajkal region by Shishlina (1997, 551; see below). Iconographic and material evidence suggest this bow developed with the domesticated horse, perhaps to protect or raid neighbouring herders (Shishlina 1997, 54-55). The short length of this bow facilitates highly effective mounted bow use, characterised historically by the Scythians, in terms of an effective

'Parthian shot' technique. Early cylinder seal iconography from southern Iraq and Iran displays highly recurved bows (Moorey 1986, Collon 1983, 54-4), whilst iconographic evidence of highly recurved bows indicates this was a prestige weapon favoured by early Mesopotamian state societies namely the rulers of Mari 2600-2350 BC (Moorey 1986; Yadin 1972, 91), and Akkad 2350-2150 BC (Khurt 1995; Durand 1983, 233 no. 295; Moorey 1986). Extant examples are found in New Kingdom Egypt, notably from the XIII dynasty to the XVIII, with examples found in Tutankhamen's tomb (McLeod 1970). New Dynasty ruler myths repeatedly portray Pharaohs wielding angled composite bows, casting arrows from moving chariots with super-human accuracy and power (Khurt 1995). In the Aegean, only a composite bow could fit the description of the great 'horned bow' which Homer describes Pandarus as using, because he 'stretched the great bow into a circle' (*Iliad* 4.105-6). A self bow would snap prior to this draw span, and a sinew reinforced bow does not contain horn. Similarly, it seems Odysseus used a composite bow to dissuade Penelope's suitors in no uncertain terms (*Odyssey* XXI).

More recent composite bows are represented by the western Asian Mongol bow, used to destroy Damascus, and key to Mongolian mounted warfare and Genghis Khan's (1162-1227 AD) success. Kublai Khan's Mongols terrorised the Japanese in 1274 AD and 1281 AD with massed volleys of arrows from composite bows. The Japanese were only saved by *kamikaze*, or great wind, which plagued the invasion attempts (Shackley 1986). The Japanese composite bow or *kyu* clearly developed from a different technological lineage than the Chinese and Mongolian bow. The Mongol bow was much more similar to the Qum-Darya tomb bow, first found in the Neolithic burials on Lake Bajkal c. 3000 BC in Siberia, which was short with characteristic 'ears' at the end of the limbs that appears to have developed into the classic Mongol and Chinese composite bow, with bone fittings (Rausing 1967, 143).

In contrast, the geographically circumscribed Japanese bow was made of laminate bamboo and lacquer - usually seven feet long - with an asymmetrically placed grip, and one that was ritually incorporated into Japanese mounted warfare prior to 700 AD (Shackley 1986; Bergman and McEwan 1997, 148). The shorter of the two bow limbs is found below the Japanese archers' grip, allowing it to be switched between both sides of the mount, matching Mongolian mounted tactics. However the Japanese manufactured a unwieldy seven foot composite bow stave, despite a consummate aptitude in manufacturing metallurgical composite technologies - such as the sword (Martin 2000). In contrast to Mongolian strategies, Japanese warriors were highly ritualised in their battles, mounted duelists called out challenges, such as 'my sword deserves a fight with yours', a few aimed shots were exchanged before a charge, prior to individual duels using swords, as detailed in the *Heike Monogotari* text originating in the twelfth century AD, in a Homeric manner (Van Wees 1996; 31. n.82). To counter the Mongol missile threat the contemporary Japanese did not attempt to copy the Mongol bows or their massed missile tactics, as it appears they were socially and technologically constrained against this. Instead they developed a shorter sword the *katana*, more suitable for cavalry charges instead of the longer *tachi* (Shackley 1986, 254). The Japanese bow achieved the performance of the Mongolian bow, but it had double the length with different materials. This indicates a different origin perhaps in a long bow, resulting in an indigenous composite bow tradition.

In a case of technological convergence, the Japanese composite bow also requires a complex thumb-grip for the optimum arrow release system, but instead of a ring like most other Asian composite bow traditions (see **fig. 2.4**); they hardened the thumb of a protective glove. Historically contingent bow making traditions at some early point became 'locked in' by a rigid feudal system, with associated material constraints (Boyd and Richerson 1985). As a result, these bows, and the associated martial art of *Kyudo* remain largely unchanged until today (Turnbull 1997).

The composite bow has been cited as key to the success of the Turkish conquest of Anatolia and the establishment of the Ottoman Empire from the end of the 13th century AD, although the Ottomans also suffered an invasion by the Mongol ruler Tamerlane in 1402 (Klopsteg, 1947; Kaegi 1964). However, variants of the composite bow are distributed all over Asia, including India and China, with a long and underestimated military contribution. This oversight by western scholars such as Hansard (1876), is part due to lack of translation of textual information into English, but mainly because of nationalistic ideas of inherent superiority (Klopsteg 1947, 5; Miller 1986, 72; Selby 2001). Roberts in *The English Bowman* notes '... no one has come close to the English longbow as the Turkish bow' (Roberts 1801; 99, 100, 101). Despite demonstrating superiority of the Turkish technology in performance terms, Klopsteg supposed the British longbow was eventually more successful in war than the Turkish composite bow because of differences in national character – repeating classical evolutionary prejudices (Kaegi 1964 cf. Klopsteg 1947, 2; Ascham 1545, 25). This view does not correlate with other historical evidence. Klopsteg and Ascham failed to mention the success of Arab mounted composite bow archers, who inflicted multiple defeats on the English during the Crusades, or that the English usually preferred to use Mediterranean yew trees for bows, which hints at separate manufacturing traditions, or that they liked Welsh archers to shoot them – hinting at another (Hardy 1976). The battle of Hattin 1187 was utter disaster for the English, who were cut to pieces by Arab mounted archers. This defeat led Richard I (1189-99 AD) to adopt the crossbow, which originated in China before 206 BC according to interpretations of Chinese tomb reliefs (Rausing 1967, 159). The crossbow proved a weapon of considerable utility to the English, especially in the heat of the Near East where longbows often weakened. Worried by the functional effectiveness of the crossbow, the Vatican had already issued an earlier Papal edict banning the weapon in 1139, describing it as a weapon 'hateful to God' not to be used against Christians and Catholics (Hardy 1976). Richard I ignored this ruling on the grounds that he was fighting pagans, and his adoption of the crossbow ensured victory at Arsuf in 1191 AD. Ironically, the *Coeur de Lion* was later killed by a French crossbow bolt at the siege of Châlus castle in 1199 AD; an event immediately seized upon by his contemporaries as Devine retribution for his own blasphemous use of a wicked pagan contraption (Hardy 1976, 35).

Upon closer analysis, different projectile technologies often have different lineages. Rather than crossbow developing from long bow, as thought by classical evolutionists (Tylor 1871, 15), the English crossbow tradition came out of John Lackland's (1199-1216 AD) search for a cost effective defensive projectile weapon, one more easily used from fortifications, and requiring less specialist training. Ignoring Papal edicts (see above), he employed the artisan Peter 'the Saracen' in 1205 to organise this which effectively continued an Eastern production lineage (Payne-Galloway 1958).

In summary, it seems 'nature red in tooth and claw' provides a rigorous technological selective environment, and that weapon systems leave a particularly clear archaeological signal. They were considered cross-culturally crucial to survival in both life and death - attested by the material evidence of war and hunt and in funerary deposits. It seems cultural assumptions of technological superiority are often unfounded when comparative systems are tested, and can constrain innovation, as with the Japanese example. If it wasn't for the *kamikaze* depleting their forces, it is likely the Mongols would have successfully invaded using a better weapon system - chance historical contingency may often have an important in technological evolution, and this has to be evaluated on a case by case basis. The dispersed pre-industrial occurrence of the composite bow found in Near Eastern, Central Asian, and Far Eastern contexts suggests multiple independent developmental pathways rather than linear progression or any single-point of technological diffusion. Near Eastern composite bow technology co-occurs with light chariots in the early Mesopotamian states – respective manufacturing technologies are very similar (Moorey 1986), whilst the other composite bow traditions have apparently co-evolved separately, e.g., with horse domestication in Eurasian steppe (Shishlina 1996), and the with the independent Japanese lineages (see above). A detailed case by case approach is necessary to qualify these preliminary conclusions, and the specific issues that this project will examine will be detailed at the end of this chapter. Before that, an examination of both the different academic traditions and associated theoretical issues currently surrounding archery technology will help contextualise the case study methodology.

2.8 Academic traditions of studying bow-arrow technology

Archery has been a subject of academic interest since Roger Ascham's *Toxophilus* in 1545, and his legacy will be discussed in detail below. Other notable works are Alfred Kroeber's survey of geographically circumscribed archers' 'release grip distributions' (Kroeber 1923, see below). Pope (1918) fathered experimental functional archery studies with his work on performance characteristics of arrowheads, whilst Klopsteg (1947) was the first to mathematically model and build optimally designed bows in terms of inherent mechanical constraints. Gad Rausing's empirical survey of the development and origins of Old World bows remains an authoritative synthesis despite ignoring the arrow's developmental pathways (1967). Graham Clark produced two seminal papers on bow-arrow technology in 1963 and 1974 which cover vast amounts of empirical ground. Miller, Bergman and McEwan conducted much experimental archaeological work comparing bow-arrow system performance characteristics (1988; 1993), and Anders Fischer extensively experimented with flint tipped arrows (1984; 1988) building upon Klopsteg's and Pope's legacy. Recently Heidi Knecht's (1997) edited volume on projectile technology has attempted to pull together disparate modern perspectives, although the bow was not studied from an explicitly evolutionary perspective therein.

To put the case study into historical context, this section explains the tradition of major academic works concerning bow-arrow technology. Although this thesis focuses upon Western traditions of archery, parallel traditions existed in the East. The antiquity of Eastern archery was underestimated by classical evolutionists who gave a Eurocentric view to most pivotal technologies. Empirical evidence from the last two centuries has since eroded assumptions of inherent Western technological superiority (see last chapter). Academic evidence of sophisticated archery traditions from the East come from several sources. Latham and Patterson (1970) translated a Mameluke work dating to 1368 AD, and Elmer and Faris (1945) translated a Arab manuscript from around 1500 AD – both detailed Near Eastern traditions concerning composite bow technologies and shooting techniques (Rausing 1967, 11). Stephen Selby recently published Chinese texts addressing composite bow techniques and the surrounding philosophical instructions that pre-date the above Arabian works, for instance the fifth century AD *Legalist Teachings* of Yang Xiong (Selby, 2001). Part philosophical tract, part martial instruction manual, these works pre-empt the earliest comparable western texts. However, as northern European archery is the ultimate subject of the case study, the antecedent academic traditions require initial clarification. The following analysis will cover the academic period up until the advent of recent functional-adaptive approaches.

2.9 Old World traditions

In England during 1511-12, Henry VIII made law all subjects under 60 'not lame, decrepit or maimed' to practise shooting the longbow (Ascham 1545, ix). Roger Ascham's politically timely book *Toxophilus*, gifted to Henry VIII in 1545 is usually cited as the first academic treatise concerning archery (but see above, Rausing 1967, 11). Ascham's work is nonetheless remarkable. Despite adopting a classical dialogue format it was the first academic text written in English as opposed to Latin or Greek. A classical don at Cambridge, he was concerned with the pivotal role of the archer in ancient history, and the social and military role of the long-bow in contemporaneous Tudor England. Ascham's was the first work of experimental archery in the Western tradition. It detailed desirable engineering characteristics for the longbow and associated tackle, gained from personal experience and interviews, and listed technicalities in order of functional effectiveness, juxtaposing a moral tale of virtue obtainable through diligent practice. Henry VIII was so impressed with *Toxophilus* (and undoubtedly its sycophantic forward, 1545 1-3), he granted Ascham a £10 yearly life pension, and appointed him tutor to Edward VI and Elizabeth I (Ascham 1545 xiii; Cully 1992).

Since Ascham, despite a few dedicated monographs (Hansard 1876; Pope 1918; Rausing 1967) European scholars generally subsumed study of the bow under the wider umbrella of general projectile technology (Knecht 1997, 3), often using anecdotal evidence to justify unverifiable lineages of technological progression following Spencer, Tylor and Morgan (see previous chapter). Tylor thought the bow was instinctive and simple. He agreed with Nilsson's view in *Primitive inhabitants of Scandinavia* (1868), where 'the bow is continued instinctively by a sort of necessity', an instinct that 'fails' in 'Tasmania, Australia and parts of Polynesia where it does not occur' (Tylor 1871, 64). Tylor was also convinced the cross bow developed inevitably from the bow, as the bow drill developed inevitably from fire-stick twisting – all unfounded statements with no empirical support (see below; 1871, 15). Tylor's optimistic claim that manufacture of stone implements is now 'perfectly understood' by archaeologists is similarly dubious after 130 years research (Tylor 1871, 65). In contrast, Morgan notes that the bow is complicated, and difficult to invent as '... a combination of forces it is so abstruse that it not unlikely owed its origins to accident... [archery] was not very obvious to the mind of a savage...' and therefore mankind had to be well in advance in the 'savage state' when the bow and arrow made its first appearance (1877, 16-17). This seems at odds with views of progress usually attributed to Morgan (see previous chapter; *contra* Trigger 1989 and Sanderson 1990). Furthermore, Morgan was the first to realise the importance of the bow in allowing prehistoric diet breadth to increase, as the bow 'permits the addition of game', although he failed to be explicit about the demographic implications (Morgan 1877, 26). General Pitt-Rivers had a professional interest in projectile weapons and coined the term 'composite bow' in a catalogue in 1897. He proposed the composite bow was developed due to lack of organic materials which would have otherwise led to the development of the self bow (*contra* Bergman 1997; Rausing 1967, 11) and stated that this type of bow had no inherent advantage over the longbow 'as long as the long bow was made of the best available materials' (Clark 1963, 50; Balfour and Pitt-rivers 1890, 242, 246-50). Performance tests demonstrate that the composite bow delivers a faster velocity projectile; although usually an universal advantage this is context dependent, as the longbow can deliver much heavier projectiles (Bergman 1997). Pitt Rivers receives closer examination below.

Early Scandinavian typologies classified vast amounts of archaeological evidence accumulated by National Museums in the 19th century. Thomsen and Montelius approached the presumed material residue of archery, namely arrowheads, as potential index fossils, chronometers for identifying spatio-temporal distributions of cultural groups, and these ideas have been refined until the present use of frequency seriation that delineates types of projectiles used to classify assemblages, notably in Danish prehistory (Vang Petersen 1984; see chapter 6). Most of the original assumptions classifying arrowheads and spearheads were intuitive or arbitrary, as recent studies of use-wear have shown (Knarrström 2003; see chapter 7).

Graham Clark (1936) in his culture history of *The Mesolithic Settlement of Northern Europe* suggested that the large number of *petit tranchet* transverse arrow heads, indicated that Ertebølle peoples definitely had bow technology (1936, 137, 148-9), although he made no connection with Maglemose bow-drills (1936, 177) as a possible indication of earlier bow technologies. Clark does not associate microliths of the previous Maglemose culture with bow technology at all, and suggests that the characteristic barbed bone points were designed as fish leisters and bird catchers (1936, 15). Unfortunately, key discoveries of well preserved organic archery tackle, bows, arrows and arrowheads found in the 20th century - were lost, stolen or destroyed during WW2. Often only reports remain, as is the case with much of Rust's 1943 evidence from Stellmoor, and Pericot-Garcia's early evidence from German and Spanish contexts (Gamble 1999 see above). After six years of horrifying global conflict, a pacifist paradigm prevailed and the study of weapons technology trailed off until the 1960's. Childe had a characteristic blind spot to conflict, and his pacific influence considerably affected research agendas (Flannery 1994, 109). Graham Clark's later work on archery signalled a sea change. In 1963, Clarke studied the remarkable Meare and Ashcott bows from Neolithic levels in Somerset that exhibited very different technological characteristics (see below), prompting his survey of all Northern European evidence for bow development. Clark's causal mechanism for development of English long bows was a simplistic invasion hypothesis, where indigenous Britains acquired the technology either when the Anglo Saxons and Danes invaded, or in the wake of the Norman Invasion at the end of the 11th century (Clark 1963, 50). He also noted the composite bow had a different developmental trajectory, to meet the needs of a 'deficient environment', echoing Pitt-Rivers causal sentiments (Clark 1963, 51). Clark later published an ambitious classification scheme for Predynastic and Dynastic Egyptian archery tackle, with the aim of classifying all African arrows into separate lineages, whilst testing sample arrows for poisons with positive results (Clark 1974; see below).

Gad Rausing's monograph (1967) focused on the origins and development of Old World bow traditions, using exhaustive qualitative ethnographic and archaeological data (1967, 14). Using an inductive empirical method like Clark, Rausing's survey suggested no single unilinear developmental trajectory for the bow. Like Kroeber's earlier culture model (see previous chapter), he saw the bow assuming a complex reticulate technological trajectory (Rausing 1967, 14). This echoed Steward's view of technology (see above). Rausing stated different bow systems could serve as 'index fossils' for culture histories, although, like Clarke he was not specific about this process (1967, 14, 21). After Rausing's work, study of Old World bow-arrow technology returned to lithic point typologists who began to utilise seriation techniques developed from Kroeber and Petrie to relatively date and hierarchically order point assemblages (i.e., Brinch Petersen 1973; Vang Petersen 1984).

The advent of New Archaeology in the US prompted a series of middle range experimental studies on bow technology in the Old World, notably Keeley's doctoral thesis on use-wear in British Palaeolithic assemblages (Keeley 1977), Hayden's publication of the first conference on lithic useware (1979), and other influential use-ware analyses of US lithic tools (Andrefsky 1998, 5). In terms of bow-arrow studies, this prompted a return to Pope's (1962) functional analyses comparing the performance characteristics of bow, where he demonstrated that flint tipped arrows had more penetrative power than a modern steel tipped arrow. Experimental work was chiefly carried out in the Old World by Bergman, Miller and McEwan, who tested projectile velocity of bow systems rather than penetrative power, which Pope preferred as a performance gauge (Bergman et al. 1988). In Denmark Anders Fischer undertook experimental use wear analyses of Danish points to determine diagnostic projectile damage for archaeologists, concluding that point evolution can be determined largely by function rather than style. Fischer saw arrow point morphology evolving in a linear manner by man's improving solutions to the balancing act of optimum penetration, the sharpest cut, and most symmetrical shape along a longitudinal axis. Fischer proposed that these functional changes were time sensitive, and presented the definitive unilinear model for point evolution in south Scandinavia from 12,500 to 3,500 BP (see chapter six, Fischer 1984; 1988).

Bow technology has since been largely ignored by Old World Scholars, typologists excepted, apart from those undertaking functional analyses. Bo Knarrström (2001, 2003) undertook micro- and macro-wear studies of projectile points from the southern Swedish Tågerup promontory in Scania, which demonstrated certain hafting assumptions made by typologists for early 'Blak' phase points were incorrect, they were in fact orientated the same direction as later Ertebølle period points. Knarrström's findings have grave implications for relatively constructed arrow point typologies in the region (see chapter five).

The Neolithic iceman found with highly expedient unfinished bow-arrow artefacts at the Hauslabjoch in the Ötztaler Alps on the Italian-Austrian Border exemplifies more recent approaches that attempt to recreate the life history of specific agents, which even with the best preservation is no easy task, as some fundamental errors were apparently made concerning pathology (Spindler 1994; 1996, 249). It now appears probable cause of death of the iceman was rapid and violent, caused by an arrow-point spinal injury, found in x-rays missed by initial analysts. Violent death by arrow is not uncommon in prehistory (Keeley 1996), and it seems plausible that bow-technology could affect populations negatively through conspecific conflict, as well as positively through increased diet-breadth in populations (Maschner and Reedy-Maschner 1998).

The study of Old World bow technology requires fresh impetus, as the material evidence has great context that is underutilised. If technological studies are to escape typological circularities of essentialist thinking a fresh approach is required. However, a return to some interesting wider technological issues raised by the early culture historians requires considerable theoretical retooling (Shennan 2000). The antecedent scholarship in the US must now be examined to understand the current approach taken in this thesis.

2.10 New World Traditions

In the New World much of the continuing interest for projectile studies arises from antiquarian concerns with lithic technologies of the 'first Americans', usually correlated with particular prehistoric groups such as 'Clovis' and 'Folsom' cultures (Parfit 2000). Origin debates comparing typologies continued throughout the 19th Century. William Holme's lithic experimental work in 1890 (1897, 61) was a methodological turning point. After reconstructing lithic reduction sequences at his Piney Branch quarry excavations in Washington he concluded that crude bifaces found there were not attributable to hand axe technology, nor indicative of 'Palaeolithic man in the New World'. Instead, he demonstrated that these bifaces were probably early stage 'rejects' during the production of much later bifacial projectile technologies (Johnson 1993, 151; O'Brien and Lyman 2000, 78). Despite permanently disabling himself whilst flaking from a large boulder, Holmes inspired many experimental archaeologists such as Don Crabtree and Francoise Bordes in a revival from the 1960's (Bordes and Crabtree 1969; Johnson 1993, 158). Anthropological bow-arrow studies took off after the sensational emergence of Ishi, last of his indigenous Yahi tribe in California, in 1911. Ishi was treated as a freak Palaeolithic survivor by the American media, and consequently lived a relatively short and persecuted life. However, he profoundly affected generations of social scientists as a consequence of being befriended by Saxton Pope (1918) and Alfred Kroeber (1923). After attending to Ishi as Instructor of Surgery at UCLA, Pope became a keen archer under Ishi's tutoring. They undertook several short bow-hunting trips, prior to two extended bow-hunting expeditions in 1913. Pope learnt avidly from Ishi's hunting skills (Pope 1918, 126). Despite his later start, Pope became a better static-target shot than Ishi, but without several years of practice Ishi could still comfortably shoot an arrow into a quail-sized target at twenty five to thirty metres, and could shoot a squirrel through the head at thirty five metres (Pope ibid., Crosby 2002, 38 n.36). Ishi's combination of skills - interrelated knowledge of bow-hunting, knapping and bow-arrow manufacturing skills remained unparalleled, and inspired Pope's technological research (Pope 1918, 104; Kroeber 1987). After Ishis' untimely death, a special volume was produced by UCLA including influential archery-related papers by Pope, who recorded comparative functional performance of different bow technologies, and measured relative penetrative success of different arrow points, although arrow velocity is a better functional efficiency indicator (Pope 1962; Miller 1988; Knecht 1997, Ch. 1). Kroeber's work followed Edward Morse's seminal monograph on archer's release techniques (Morse 1885; Kroeber 1923). Kroeber put Ishi's unusual 'thumb-grip arrow release style' into the context of other arrow grip releases around the world, noting that with the exception of Ishi, the thumb-grip release was solely associated with Near Eastern and Eastern technologies associated with the composite bow.

Paul Klopsteg, a US army Ballistics physicist applied formal mathematical modelling of aerodynamics to bow arrow technology, with the aim of making the optimum long bow-system (see below) given the current material constraints (Klopsteg 1935; 1943; Hickman 1929, 1937; Hickman et al. 1947). Klopsteg identified and minimised the 'archers paradox' where bows can inefficiently transmit stored energy to the arrow upon release of the string resulting in undesirable 'arrow-wobble'. The results of Klopsteg's work with Forrest Nagler, a mechanical engineer, and Clarence Hickman, of Bell Laboratories (Hickman et al. 1947), indicated that optimum bow designs conform to wide-limbed flat bows of the Mesolithic and Neolithic shaped by stone tools, rather than later round cross-sectional medieval designs shaped by metal tools. This does not indicate a simple linear trajectory for bow evolution through time (Bergman 1991, 79). Klopsteg then became preoccupied with obtaining the longest arrow cast, realising that he had little chance of 'perfecting' the bow without obtaining and replicating the traditional knowledge of Ottoman

Turkish Bowyers. After considerable research he published *Turkish Archery* in 1947, noting the composite bow had roughly twice the cast of a reinforced bow, the longest shot was recorded in 1798 by Robert Ainslie ambassador to the Ottoman port by the Sultan Selim of 972 yards, two inches (or 889 metres; Crosby 2002, 77). Perhaps this particular record was another Pharaonic-style myth analogous to those found in New Kingdom records (see McLeod 1970), however Klopsteg lamented that even recently verified Turkish archery records remained 'unbroken by humiliating margins' (Klopsteg 1947, v). Turkish construction principles had to be refined if any greater cast was to be achieved, although it would require synthetic materials to do so (Klopsteg 1947, v, 157). Despite calculating and building optimum designs for the bow-arrow, bowmen of Klopsteg's era couldn't replicate the cast of the Ottomans. This suggests improvements in bow technology are not inevitable, and are historically contingent upon differential social learning lineages.

Since Kloptsteg's engineering studies of the 1940's (especially Hickman et al. 1947), formal models and experimentation have been increasingly used to verify previously intuitive typological assumptions made in archaeological case studies. An example is the argument between A.V. Kidder and Jim Browne during the 1950's. Kidder noted heavier projectiles were found in chronologically earlier deposits than later smaller points, under rock shelters in the US Southwest. Heavier points were attributes to earlier atlatl darts, lighter points to later arrows – Kidder assumed unilinear technological development from dart to arrow (Kidder 1938, 156). Browne, an experienced bow hunter, demonstrated the heavy Folsom point made an excellent armature for an arrow through experimental reconstruction (Browne 1938, 358). This acrimonious classification debate went on, fuelled by Franklin Fenenga's proclamation that because ethnographic instances of north American arrows were always smaller, thinner and lighter than spear tips, archaeological counterparts must have belonged to different weapon systems (Fenenga 1953). Fenenga weighed lithic projectile point assemblages, and explained a resultant bimodal distribution in terms of points being either darts or arrows. This 'fact' is echoed by Rozoy (1989) concerning the Old World Mesolithic point data, who states unequivocally and without experimental support, that armatures over five grams are not arrows, Mesolithic arrows were always 20-30g, as a heavier tip would unbalance them, and the geometric character of the points is of no significance (1985, 13). Ethnographic examples of very heavy Yąnomamö arrows suggest other possibilities, so without 'middle-range' experimentation to support such claims, this is a non-argument.

In contrast to NW Europe, US scholars looking at hunter-gatherer subsistence in arid regions are often confronted with surface scatters of points, so they devised ingenious experimental and quantitative techniques to help infer their function, and their particular weapon systems. The debate continues between 'empiricists' who measure the data, and 'possibilists' who experiment with replicas (Christensen 1986, 113). Thomas measured a number of known lithic darts (n.10) and arrows (n.132) from ethnographic collections; he estimated the respective point weights from their continuous variables using linear regression (Thomas 1978). Results demonstrated considerable overlap between two projectile systems, when weight was used as sole distinguishing criteria. Thomas concluded that this single variable was insufficient to determine function - however he did demonstrate that lithic darts were usually heavier than lithic arrow heads (Thomas 1978, 467). Christenson was convinced that the two systems were distinguishable through metric analysis of the arrow head, and demonstrated that basal neck width of arrow head and its weight can be strongly correlated to its function (Christenson 1986, 114-117). This method was refined by Shott using a more convincing statistical technique to quantify differential projectile point classes by discriminant analysis (Shott 1993; 1997). This discussion of point-variable analysis will be expanded upon in chapter five; suffice it to say that if variation in point morphology can be accounted for in terms of contemporaneous environmental and resource change, more secure interpretation of cause and effect concerning technological change is possible.

Fenenga's (1953) simplistic assumption that atlatl is automatically and quickly replaced by the bow has since been refuted, as Fawcett recently demonstrated over a millennium of simultaneous co-usage of bow and atlatl systems in southern Idaho (Fawcett 1998). Fawcett's study measured 54 projectile point neck-widths, from a series of ^{14}C dated archaeological assemblages. He obtained a clear diachronic bimodal distribution of this continuous variable, indicating that darts and arrows overlapped chronologically (Fawcett 1998, 72). The only over substantive conclusion he made was that a generally reducing neck width is time sensitive in his case study. However, despite Fawcett's identification of co-usage of weapon-system, the reason why this occurs is studiously avoided. One could suppose dual weapon system (if indeed it was in the same group) was due to a different prey-specific practice. Alternatively, it may be that that different projectile weapon traditions can coexist without an inevitable rapid replacement, if for instance, directional selection was not acting strongly. For groups with both bow and spearthrower systems, it may have been that selection was acting weakly during the long transmission, perhaps due to minimal associated prey-resource stress, and that the lithic raw materials were in abundance and that larger and more wasteful lithic dart points were therefore not an economic issue to be solved by abandoning a traditional weapon system. Unfortunately, this is pure conjecture as these complex issues remain unresolved. It is proposed that population linked cultural transmission processes are probably key to these technological changes - selection need not be invoked, however it must be accounted for (see below). A detailed description of the diachronic selective environment is therefore required, prior to hypothesizing convincing explanations for change/stasis within weapon systems.

New analytical techniques following the pioneering micro-wear work of the Russian Sergei Semenov (1964) proposed experimental work could resolve point-function (Andrefski 1998, 191). Implications were that certain projectile systems may leave differential signatures on their lithic point components. This allowed the potential problem of point reuse and re-sharpening to be addressed, as archaeologically deposited arrow points may have undergone a range of identifiable functions throughout their life-histories - as long as post-depositional processes could also be identified or excluded from conclusions (Andrefsky 1998, 191; Peterkin 1993; Ahler 1971, 108; Nance 1971, 365; Greiser 1977, 114). Microliths used as drills, chisels, or projectile points can exhibit characteristic use wear. Projectile points have since been shown to show evidence of distinctive lithic 'spin offs' and impact damage, where high velocity impacts compress the stone, leaving diagnostic fracture patterns (Fischer 1984; 1988). Andrefsky notes that small bifaces are less likely to be used for purposes other than projectile tips; however, the use life of 'Dalton' tips shows that they have been re-sharpened to such an extent that they conformed to the morphology usually associated with bifacial drills (Andrefsky 1998, 192). Although fallible, these methods can help determine point orientation on the haft, as diagnostic compression fractures and ripples can occur in the basal area when arrows impact, whilst spin-offs and impact fractures peculiar to the point tip can also be identified. Point re-use is more of a problem with sturdier points using bifacial technology (Nassaney and Pyle 1999), rather than microlithic bladelets which cannot be reduced in size and retouched as they are already small (Grøn 1982; Fischer 1988; Knarrström 1993). A case by case approach is clearly necessary due to potential variation in point function. However, the majority of points used in the following Scandinavian case study are manufactured using the micro-burin technique and are not severely damaged. They also have hafted examples with diagnostic knock ends, and the arrowheads rarely show signs of secondary retouch in terms of resharpening, and can display characteristic use-ware diagnostic of projectile damage (see next chapter).

As detailed in chapter one, Julian Steward's post-war approach to specific technologies such as the bow was less concerned with origin and diffusion arguments, than with contrasting ecologies and differential social contexts. Cultural ecology was concerned with cultural adaptations to the environment. Different environments necessitated different hunting strategies, even when the similar bow technologies were found between populations. Steward saw these culturally driven technologies as limiting the social composition and the demographic ceiling of a group (Steward 1955, 38). Steward's acknowledgement of technological complexity is in contrast to Leslie White. White saw the bow, like other technologies, simply as 'mans' extra-somatic means of adaptation', describing technology as part of an essentialist thermodynamic law explaining culture change. Binford, following White, saw technology like the bow as a simple cultural adaptation, and the advent of New Archaeology catalysed efforts to create a unifying projectile point classificatory system, with varying success. By the 1960's a multitude of regional point typologies existed in the US, often designed solely as a heuristic device by excavators, but certain shapes regularly assumed the canonical status of cultural index fossils, representative of ethnographically analogous groups (see below). Binford initiated his career by creating an exhaustive classificatory list of potential projectile shapes, which was promptly ignored by his peers (Binford 1963). His aim was to describe shape avoiding 'the pseudo-problem of types' as existing typologies were not explicit on the reasons why they worked. Each classification was meant to be fed into computer by punched card for central storage, presumably with the un-stated aim of a unifying typology, but the optimistic system was never adopted, due to entrenched regional schemes (Binford 1963, 220). More recently Thomas designed a similar system that has been widely praised (Thomas 1978, 461; Shott 1997; O'Brien et al. 2001). Binford acknowledged it was his naivety towards these rooted lithic typologies that prompted him to study faunal assemblages with more inherent variation (Johnson 1993, 159). Typological arguments still rage in the US concerning functional and stylistic arrow-point attributes, and increased computing power has prompted O'Brien (et al. 2001) to create a similarly 'paradigmatic' classificatory system without typologically derived preconceptions, with cladistic theory, to create the most parsimonious phylogenetic history of US projectile points (see below). Although Binford, Thomas, and O'Brien all attempted to be as objective as possible, the paradox remains that any relative classificatory system has some inherent preconceptions regarding functional constraints

(Knecht 1997, 3-7; Beck 2001; O'Brien and Lyman 2001; Bettinger and Eerkens 1999; see chapter five).

Robert Musil proposed that all aspects of lithic point technology were best explained in terms of functional traditions. Points were adaptive rather than representative of specific cultural groups, or as prey-specific ecologically constrained adaptive responses (Musil 1998). Musil examined three different point traditions in North America, fluted/lanceolate, stemmed, and notched. He proposed that instead of being cultural signifiers, engineering traits were purely functional in terms of improvements to previous traditions. Trait variation was not due to migrations or adaptations to a specific hunting economy - just a functional progression - and that this explains why the differences in Palaeoindian artefact assemblages and subsistence adaptations were seen primarily in their point shapes, rather than in the remainder of their toolkits (1988, 385). Recently this approach has been expanded upon by Metzler (1981), who stated that lithic scraper morphology can also be explained in terms of functional characteristics; similar shapes can be explained in terms of similar artefact use, rather than as diagnostic of group affiliations. Recent approaches have been even more explicit as to defining cultural process, rather than cultural affinities, as seen with Hughes (1998) functional analysis of projectile systems, and O'Brien's (et al. 2001) cladistic analysis. Hughes proposed that the spearthrower weapon-system was superseded by the bow-arrow, through comparison of various functional characteristics and stratified lithic point remains, from ^{14}C dated assemblages in the Mummy Cave rockshelter in north western Wyoming (Hughes 1998). Performance characteristics were collated from extant experimental studies for four weapon systems; thrusting spear, thrown spear, spearthrower, and bow-arrow. Hughes then calculated predictions for expected ranges of characteristic variables for each weapon-system. The bow was seen to be an inherently more functionally effective technology than all the other projectile-systems, due to its greater versatility, portability, and velocity of the arrow (Hughes 1998, 393, 396). Again, smaller arrow points were seen to 'cost' less than the other weapon-system's points, as they could be manufactured relatively quickly from larger flake spalls (see also Fischer 1984; 1988). Points from the case study data fitted well with Hughes' predictions for both arrow heads, and spearthrower dart-tips. The results were derived from a combined total 391 points (from 23 stratigraphic levels - n. 219 tips were fragmentary), and indicated that arrows probably replaced darts sometime between c. 2000 and 1300 BP, although how long any transitional period lasted between the two periods was unclear. Although Hughes went a considerable distance to demonstrate a relative selective advantage for the bow on sound engineering grounds, importantly, the fluctuating selective environment was not accounted for. In effect, there is no inherent causal mechanism for technological change presented by Hughes, other than selection. This study does not go far enough, as the complex role of population and environment is effectively ignored, and although there is a good empirical account of probable technological replacement horizons, this ultimately fails to explain why technological changes occurred. Similar criticisms can also be levelled at O'Brien's (et al. 2001) paper, a complex cladistic approach to the evolution of lithic point technology. O'Brien's study of n.621 south-eastern US Palaeoindian points dating from c. 11,500 BP (without stratigraphic context), used an advanced statistical cladistic clustering technique to order point traits in terms of closeness of relation ship to one another, that aimed to avoid classifying certain points as essentialist cultural kinds. Seventeen projectile artefact classes were duly created, each containing eight unweighted characters which were treated as independent by the analysis, although they were probably linked mechanically in some way; and any link between variables could have biased the results (O'Brien 2001, 1126). Great care was taken to create class criteria (e.g., by using ratio variables instead of continuous numeric variables) which did not assume any prior hierarchical arrangement. This method is termed paradigmatic class construction, where classes are created solely by the intersection of dimensions (O'Brien 2000, 402). O'Brien's aim was to create point classes that reflected variation due to transmission mechanisms, rather than other processes, such as lithic re-sharpening. When the cladistic analysis was run, a series of possible artefact lineages in the form of hypothetical phylogenetic trees were generated. The results presented allowed the most parsimonious tree to be identified, and therefore potentially falsified, in the event of new data being obtained from the archaeological record. Again, like Hughes, O'Brien cleverly describes a probable evolutionary lineage using his case study data, however, he does not explain *why* the particular ordering occurs. The danger remains that the class construction used, despite every effort to avoid it, could be as circular a methodologically as previous typological systems - this remains an empirical matter to be tested (see chapter five). Although cladistics is clearly a powerful classificatory tool, and projectile-point classes were constructed to be consistent with O'Brien's evolutionary archaeology method, environmental considerations remain to be accounted for. As he states himself, cladistic method is only a solid starting point (O'Brien 2001, 1134).

The lithic points in the following case study do not allow paradigmatic class construction to the same extent as O'Brien's (et al. 2001) bifacial projectile points, due to the inherent lack of morphological variation in the Scandinavian projectile points (see chapter five). In other words, there are not enough potential character states available, so cladistics would be an inappropriate method to adopt here (Mark Collard, pers. com.). However, because the point data in the following case study has good associated ^{14}C data, a secure chronological and relative ordering of the point assemblages is obtainable without the use of cladistics (see chapter four).

2.11 Definitions, distributions, and unit of analysis issues

As often part of a large suite of prey-capture technologies within any given group, the bow allows a comparatively greater flexibility in prey-capture ability - it allows potential increase in mobility, and reduction in encumbrance compared to its prehistoric projectile system alternatives (Hughes 1998). The bow can potentially increase the effective diet breadth in a way that other projectile systems cannot - the effective carrying capacity of a given environment is increased, although this remains an empirical matter that has to be tested on a case by case basis. The atlatl spear-thrower system is generally speaking functionally inferior, as although reconstruction experiments show it is very effective on large prey, the relatively large movements required for optimal spear cast means it is not as silent or stealthy, and has reduced number of shots per minutes compared with the bow (Bergman 1993). However, the two systems are not always mutually exclusive as has been demonstrated by Fawcett (Fawcett 1998 see above; also Shott 1997).

Bow-arrow technology is geographically ubiquitous throughout prehistory, although apparently absent in parts of Polynesia and pre-contact Australia (Cattelain 1997, 220). However, archery is far from being a 'simple' adaptation, or in any way inevitable, as implied by Service (1971). Different lineages of bow-arrow technology vary in complexity from one-piece wooden bows (simple, long, or self bows) found in Mesolithic contexts in Scandinavia, and the contemporary Yąnomamö; to the complex laminated bows of bone, fish glue, horn, gut strings, and bindings that comprise the composite bow found in the Eurasian Bronze Age and contemporary Mongolia (Shishlina 1997). Similarly complex is the composite nature of most arrows which comprise a 'nock end' for the bow string, with optional fletching, main-shaft, fore-shaft, bindings, glue resin and/or binding for a shaped or moulded projectile point, all with elaborate decoration in many cases. Even in the most 'simple' non-state cultures, bow-arrow usage and associated hunting strategies are highly complex, not only in terms of artefact construction, but of the suite of associated learnt behaviour. It takes years to obtain adequate skill in bow use and manufacture before hunting is productive in most if not all non-state societies. Walker (2002 et al.) recently noted that the hunting performance with bow-arrow system peaks surprisingly late in life, after peaks in strength; for instance between the ages 45-50 for the Hadza, and between the ages of 35-40 in the Eastern Paraguayan Ache, and over 30 in most other ethnographically recorded cases (Walker et al. 2002, 639), indicating that the combination of skills required to maximise prey return rates take years to acquire. Ishi, last of the Californian Yahi tribe, also demonstrated that age and experience provided a hunting advantage, to a degree. Saxton Pope commented from their shared hunting experiences, that although Ishi was an average shot, in his middle age (although his age was indeterminable in absolute years), he remained a consummate stalker, with a remarkably high return rate (Pope 1918). Like many traditional technological skills, ethnographic evidence shows bow manufacture and use is usually segregated by sex, taught vertically from parent to offspring of the same sex, and learnt from childhood through adolescence. It is safe to say that the whole inter-generational transmission process concerning bow-arrow technology is lengthy. It takes many years in most tradition societies to master the technological complexities of bow-arrow manufacture and hunting, which usually follow a vertical transmission pathway, one that is often seen to start in very early childhood, and continues on into the teenage years, and beyond (Pope 1918; Shennan 1996; Walker et al. 2002). Rather than being a straightforward diffusion, it follows that new and old technologies can be subject to many different cultural processes. Bow arrow technology is historically contingent, subject to drift and selection at various scales, and constrained by cultural traditions and technological constraints. Potential variations in these processes, as indicated throughout this chapter, suggest that a case by case method is essential.

An ideal case study will use a chronological framework not reliant on typological or relative dating assumptions. A study area with well established arrow typologies for cross referencing absolute dated results is informative, as is one with evidence of a long history of continuous occupation in a relatively small geographic area, so lineages of projectile traditions are likely to be homologous, rather than analogous. Radiometric modelling of phases of different types of contemporaneous data can provide a time stepped series of contiguous assemblages, to test the impact of population models. Mesolithic Scandinavia has the earliest extant projectile point data with sufficient radiometric and projectile point data available for this purpose.

2.12 Summary: Case study

This final section presents the key issues for the proposed Mesolithic south Scandinavian case study.

Multiple developmental pathways for bow-arrow technology are apparent, and due to this variability assumptions concerning any simple linear evolution of bow arrow technology is unwise. Case specific testing of technological change is required, and the prevailing paradigms of technological development require closer scrutiny, in terms of the precise evolutionary processes that could have been involved. Arrowhead morphology may or may not correspond with ecological changes, this is an empirical matter. In the first instance, a absolute chronological ordering of point assemblages is a key issue; new statistical techniques using extant ^{14}C data can test extant typologies given enough associated radiometric data, as chapter four will demonstrate. Chapter five will then analyse the variation in point shape point shape morphology in and between the case study assemblages. Following Ellis (1997), ethnographic evidence suggests that lithic arrow heads are likely to have been designed for use on humans and ungulates; when faunal remains are associated with the case study arrowhead assemblages, this data may help interpret point function. It is proposed that with enough associated ecological data, environmental context can demonstrate whether point shapes could have changed in relation to faunal distribution and diet breadth changes. It follows that directional selection working on functional traits can improve prey-capture rates and/or increase diet breadth, so local populations would increase as a result. Traits not subject to selection are therefore subject to stochastic drift processes which may be archaeologically recoverable. However, accounting for drift and selection is not a simple matter, as the dearth of associated evolutionary archaeology case studies demonstrates (following Dunnell's 1978 paper). It is proposed that the use of a linked series of integrated and focussed environmental and population models will provide a more convincing explanation of bow-arrow technological evolution. Following Shennan (2001, 2002), technological changes can closely correlate to population fluctuations; it is clear that population crashes can explain loss of complex arrow-head technologies through stochastic drift processes, although these are not always straightforward, and again, require a case by case approach that accounts for specific environmental fluctuations (Henrich 2004).

In conclusion, bearing in mind the problems with previous case studies, this project has focussed upon choosing a region with a number of well excavated contemporaneous sites, multiple sealed archaeological levels with excellent radiometric data, many associated faunal remains, and a statistically viable number of complete lithic arrow points in each sealed level. The relative time stepping of both projectile point and osteological assemblages is a key aim - this is essential if the subsequent models are to be integrated in a meaningful manner. The case study method has focussed on constructing a chronological framework not reliant on prior typological assumptions, in a geographical area with well established arrow typologies available for cross reference. A quantitative analyses of time stepped point assemblages can then be made to determine the extent of intra- and inter-site point morphological variation. Quantitative reconstruction of diet breadth changes and relative faunal distributions are made to see if certain projectile point traits are likely to be adaptive or not; for instance, where changes in point shape correlate with certain prey types. Demographic reconstruction is thought to be key, so population models are constructed that may explain technological changes in the case study region. Finally, reconstruction of the case study palaeoenvironment is undertaken, to see whether this could provide an underlying causal mechanism for technological evolution.

Chapter 3. Case study:
Mesolithic South Scandinavian bow-arrow technology

3.1 Introduction

This case study is divided into three chapters. This introductory chapter puts the case study into historical and ecological context, and presents the sites and assemblages used.

Chapter four explains chronological problems with current relative typological dating methodology in the case study region, and presents a new absolute chronological model based on Bayesian statistical principles that time-steps nine projectile-point assemblages in terms of their absolute radiometric data and archaeological context.

Chapter five describes the inter- and intra-site projectile point morphological variation. It explains previous quantitative approaches to projectile point morphology, presents the current method, then gives the results extrapolated from the case study material.

Chapter six analyses the extant palaeoenvironmental data in terms of point morphological variation, and presents an evolutionary model in terms of fluctuating population levels that can explain the technological changes described in chapter five.

This chapter introduces the middle Mesolithic South Scandinavian case study data, obtained from extant material from excavation of nine site phases in southern Sweden and north eastern Denmark (see the case-study area map **fig. 3.1**) More archaeologists work in Scandinavia than any other country, consequently a large amount of environmental data is available to contextualise the current study. Caution is required, as despite a wealth of well preserved assemblages, there is a wide variation in terms of data quality (Price 1991).

An initial overview of the case study region in terms of broad environmental change to postglacial Mesolithic Northern Europe is then followed by a summary of south Scandinavian Mesolithic environmental and settlement evidence. Previous cultural paradigms for lithic technology are described. An overview of the extant evidence for bow-arrow technology is then presented, followed by a summary of the case study sites, phases, and data. A final section explains how the data will be related to evolutionary meta-theory in terms of the conclusions of the previous two chapters.

3.2 Postglacial Mesolithic Northern Europe

From 16,000 BP, the final Pleistocene in Northern Europe is now characterised by climatologists as a period of continuous warming from the Late Glacial Interstadial, only interrupted by the Younger Dryas Stadial. The land was locked by glacial ice sheets until the end of the Devonsian/Weichselian at around 14-13,000 BP, when the sea level was 60m lower than today. After complex changes, by 5,000 BP many coastlines were like today but higher, and further inland. As mean temperature rose swiftly, southern Scandinavia emerged from the arctic tundra through a complicated process of eustatic sea level rise coupled with isostatic land rise or rebound, which dramatically varied according to different geological factors, and still continues in certain Scandinavian locales (Grøn 1987; Christensen 1995; Price 1991, 215).

Highly diverse and rich environments emerged in the wake of the retreating ice, with new coast lines, lakes, marshes and forested environments allowing a plethora of new species to colonise them. Northern Europe was covered by glacial sediments facilitating colonisation by a grassy steppe tundra with dwarfed birch and willow followed by open birch forests, then by mixed birch-pine forest with other species such as ash, aspen and elm, as disclosed by pollen analyses (Karsten and Knarrström 2003, 22; Regnel et al. 2001; Price 1991, 214; Huntley and Birks 1983; Birks 1981). The Boreal pollen zone period was characterised by the appearance of hazel-pine forest, temperatures became similar to today. Boreal bog sites dominate the extant archaeological record, such as Maglemose, Holmegaard Mose, Sværdborg Mose in Denmark, Bare Mose and Ageröd Möse in Sweden and Star Carr, Mt. Sandel, and Thatcham in England (Larsson 1978). However, many submerged coastal settlements have received increasing attention (Pedersen 1997; Fischer 2001). The period is characterised as generally warmer than today (18-20°C). The arctic tree-line moved northwards, whilst elm declined probably through disease. Rapid sea level rises had dramatic affects on long term human settlement patterns, as many Danish and Swedish Mesolithic coastal settlements are now underwater, whilst new inland environments allowed different resources to be exploited by local and non-local populations (Larsson 1983; Sørensen 1996; Fischer 2001). The ameliorating climate was highly favourable to hunter-gatherer groups. Recent settlement evidence suggests larger sedentary groups were the norm for the late Pleistocene and early Holocene, rather than the smaller mobile groups that ethnographic comparisons have often predicted (Price 1991, 211; see chapter six). Faunal evidence suggests that arctic species, notably reindeer, were confined to higher elevations of the frozen North, whilst new local species precipitated an economic shift from aurochs and elk in the Preboreal, to red deer, wild pig and roe deer. An abundance of fish, foul, sea mammals and small fur bearing mammals also flourished and were exploited. Predators such as wolves could be seen as occupying a very similar ecological niche to humans and were in competition for similar resources (Carter 2001). Perhaps a result of continuing close environmental proximity between scavenging wolves and humans, dogs were domesticated early (Larsson 1988), and were likely to have formed a key part of contemporaneous bow-hunting hunting strategies, either through baying or tracking (Carter 2001; Karsten and Knarrström 1993, 59).

3.3 Traditional cultural divisions

Cultural groups in the Northern European region are traditionally divided on simple stylistic grounds into typological techno-complexes (see fig 3.2), often in terms of a distinctive lithic projectile point typology. This is demonstrated by Brinch Petersen's early work (e.g., 1973), and the subsequent work of Vang Petersen (e.g., 1979; 1984; 1999; see **fig. 3.2**). Each culture is usually named after a type-site referring to a distinctive type of lithic artefact or combination of artefacts, e.g., Kongemose, usually classified by a specific lithic reduction technique, or a proportion of artefacts with certain technological characteristic (e.g., hard or soft hammer), which is then assigned a general geographic area and chronological period. This unilinear method can be atheoretical, and gives rise to complicated and often confusing nomenclature. Ethnonyms help describe technologies and periods in broad terms, but require more careful qualification on functional grounds when dealing with technological traditions, as previously shown (and see chapter six). For instance, the initial post-glacial settlement period in north west Europe is classified as being characterised by Bromme, Federmesser and Ahrensburg/Early-Maglemosian (Hensbacka/Fosna) techno-complexes that had connections with southern Scandinavia around 10,000 BP (Andersson and Knarrström 1999, see **fig. 3.3**). These groups initially cover over 100,000 km^2; **(see fig. 3.2 and fig. 3.3)**. The number of defined groups and styles increases to more than 15 by the Late Mesolithic, certain techno-complexes can cover areas of less than 1000 km^2 (Price 1991; Vang Petersen 1984, 16; 1999; see **fig. 3.2**). Intuitively, this seems highly indicative of increasing population densities, and this is a theme that will be returned to in chapter six.

Culture historical paradigms dominate phase descriptions in the case-study area, resulting from the both the distinguished history of Scandinavian investigation, and a preoccupation with typology, stemming from the need to classify and order vast Mesolithic collections, especially at the National Museum in Copenhagen. In Danish contexts (see **fig. 3.2**), a series of relatively derived chronologies have been developed since the preliminary investigations of the first 1848 'Kitchenmidden Comitee', set up by the Royal Danish Academy of Science (see chapter three; Trigger 1988, 82). Nonetheless, important sites still remain unpublished (Brinch Petersen 1973, 78), as is the case study site of Månedale, whose projectile points are used below. Swedish traditions dispute the Danish phases, as they often fail to conform with Scanian evidence - consequently single artefact cultural classifications are treated with caution here. Becker divided the Middle Mesolithic into three phases (1939), Brinch Petersen into four (1973, 92), Andersen into three (1970; 1975), Vang Petersen into five (1984), whilst Sørensen (1996) has added an earlier phase to Vang Petersen's scheme. All these phases are primarily defined by a type site's arrowhead morphology, either qualitatively, or quantitatively using seriation (see next chapter; Vang Petersen 1984, 9). A good illustration of the continuing cultural importance given to projectile points is provided by Fischer's linear diagram of projectile point evolution, and this will be returned to in chapter five (Fischer 1997; see **fig. 3.4**).

The major chrono-spatial names of relevance to the case study are Maglemose, Kongemose, and Ertebølle phases, in that temporal order (see **fig. 3.3**). South Scandinavian cultural phases are usually named after Danish 'type sites', defined mainly by particular proportions of lithic blade technologies and artefacts. For instance, large tanged biface points of the Bromme period are replaced by microlithic blade technology in the early Maglemose period (see **fig. 3.2**). Complex indirectly punched long blades and micro-burin technique characterise the Maglemose, and especially the regular rhomboid and oblique points of the Kongemose assemblages, whilst Ertebølle assemblages are dominated by cruder blades, generally produced by direct hard hammer technology (Brinch Petersen 1973, 83).

3.4 Middle Mesolithic arrowheads

The vast majority of case study points come from the Middle Mesolithic phases which are divided up mainly by arrowhead morphology (see **fig. 3.5**). This is because of the ubiquity of the arrow head, generally due to its thin blade technology, and small size that generally prohibits repair, rework or re-sharpening (Vang Petersen 1984, 9). The Danish typological scheme subdivides the Kongemose phase into Blak (rhombic oblique points), Villingebæk (large rhomboid oblique points), Vedbæk (narrow rhomboid oblique/big oblique points), Trylleskov (small oblique points) for the Early Ertebølle phases (see next chapter; Brinch Petersen 1972; Vang Petersen 1984, 10; Sørensen 1996). A variety of technological details have been used by Vang Petersen to distinguish relative phases through frequency seriation, using ratios of percentages of continuous morphological variables, including presence of retouch, basal shape, internal angles, and sinistral or dextral orientation (1984, 9). Controversially, Karsten and Knarrström (2003, 135) note the Danes have recreated a Mesolithic typological scheme previously formulated from Scanian material by Carl Axel Althin (1954), as Althins's II D phase and III D phases correspond to the Danish Blak and Villingebæk phases respectively.

Despite a paucity of hafted arrowheads, Maglemose, Blak, and Kongemose phase points are traditionally seen as obliquely hafted, see **fig. 5.5.C**, whilst Ertebølle points are transversely hafted on arrows (see **fig. 5.5.B** and chapter five). Lars Larsson has studiously avoided applying fine-grained arrow point typologies to Swedish assemblages. Kongemose phases are typologically defined by very regularly shaped small points that are assumed to be obliquely hafted arrowheads. However, no hafted Kongemose arrowheads survive, despite later and earlier examples. Nonetheless, fine inter-group distinctions are made by Danish projectile typologies, which Vang Petersen based largely on Kongemose relative arrow point morphology (1984, 7). He spatially related these types to language dialect groups, following Birdsell (1968) and Wiessner (1982). Vang Petersen's frequency seriation broadly correlates with absolutely dated deposits of artefact classes in Danish deposits available at the time (Vang Petersen 1979, 1984), building on Brinch Petersen's earlier seriation work (1973); this method is discussed critically in chapter five.

3.5 Settlement and population

Rowley-Conwy noted that sedentary groups would out compete their mobile counterparts, due to extended weaning time characteristic of more mobile groups, as they would be less likely to recover from population crashes due to their longer spacing of births (Rowley-Conwy 1983, 114-5). It appears that long periods of settlement with larger populations than previously thought are likely throughout this period, and the vast number of finds from the Tågerup promontory bears this out (Rowley-Conwy 1983, 114; Karsten and Knarrström 2003). Changes in spatial organisation of Early to Late Mesolithic dwellings and relative increases in the m^2 area of dwellings appear to support an associated shift in social organisation that suggests an overall increase in the number of nuclear families in households, whilst the distance between households is seen to decrease (Grøn 2004, 714, figs. 13, 14). Although ethnographic evidence of hunter-gatherer household organisation indicates it is dynamic phenomena that does not always follow predictable trends (Grøn 2004, 713), the dwelling data may also be evidence of an aggregate expedient reaction to population increases linked to greater sedentism, as more people occupy the optimal - or perhaps the traditional - ecological patches.

Recent archaeological excavations at the Tågerup promontory indicates very large year round settlements, and largely sedentary populations, more analogous to Ames and Maschner's 1999 description of first-contact settlements in Canadian North West Coast populations than of smaller ethnographically known groups (Ames and Maschner 1999, Carter 2001, Magnell 2001; Karsten and Knarrström 2003). Faunal osteological evidence increasingly supports year long site occupation, through seasonal tooth patterning, indicating month of birth, and age at death (Carter 2001), following Rowley-Conwy's re-evaluation of the evidence of seasonality from Star Carr (see Rowley-Conwy 1987, 75 fig. 6.1). The phases of the case study are all from the Atlantic pollen zone period, Middle to Late Mesolithic. Coastal sites were previously interpreted as short occupation duration due to certain artefact inventories from selected phases. Osteological evidence from the Vedbæk project in Denmark (Vang Petersen 1984, 7) and recently the Tågerup excavations in Sweden (Karsten and Knarrström 2001, 170) suggest continuous occupation horizons once the new promontories were occupied. Certainly, large groups were present in Nivå, and Vedbæk, and Tågerup throughout the Middle Mesolithic, and elsewhere in the later Mesolithic (Carter 2001; Karsten and Knarrströme 2001, 170). It seems permanent settlements were usually placed close to the edge of the water to exploit as many natural resources as possible, although contemporaneous sites have also been found inland by lakes (see below). Where phases with lithics have no supporting evidence of year round occupation, this will be made explicit below.

Previously, low ethnographically derived population densities for prehistoric hunter-gatherer groups became archaeological doctrine following the dissemination of the *Man the Hunter* volume (Lee 1968; Price 1991, 230). These low population estimates need to be re-evaluated. However, the question of how these (large) populations fluctuate through time remains crucial to understanding technological change associated with archery traditions, and this problem will be modelled in chapter six.

A phase by phase approach to projectile point technology is taken below, one that assumes no linear sequence of technological development. In this manner, radiometric and environmental data from the same levels can be compared on a like for like basis.

3.6 Overview of case study sites and phases

This section is a summary of the nine assemblages used in the case study area, their distribution is seen in the case-study area map (see **fig. 3.1**). In total, the case-study phases contained a combined total of c. 3600 complete lithic armatures from the south Scandinavia middle Mesolithic (c. 6600-5400 BC). Each phase is described in terms of associated fine-grained archaeological data and previous interpretations. Despite the ubiquitous arrowheads, it must be noted that these phases vary drastically in terms of amount of contextualising environmental and osteological data and supporting publications.

The Danish material consists of point data measured from the University of Copenhagen and the National Museum and contextualising data from extant site reports. Sørensen's 1996 *Kongemosekulturen i Sydskandinavien*, was an invaluable source of data, as was Peter Vang Petersen's exhaustive 1979 dissertation, which later produced the standard typology for the region through frequency seriation (Vang Petersen 1984).

The Danish sites used in the case study were mainly excavated using a 'crossword' method of metre squares, which was a method developed to discover the maximum size of the area of interest, without the need to excavate the entire area; see **fig. 3.6** After metre square test pits are dug at regular intervals over the area of interest, and an area of particular interest is found, i.e., a probable settlement or refuse layer is found, an intersecting horizontal X axis, and a vertical 'Y' axis of metre squares are excavated, relative to magnetic north (N). This enables a standard estimate of settlement size to be calculated, whilst reducing the extent of the excavation to a minimum (Vang Petersen 1979, Pers. Com.). Typically, Middle Mesolithic sites consist of a settlement area and an adjoining refuse area, whilst Ertebølle sites are often seen to have refuse mixed into the settlement itself. The Danish points from all sites except Stationsvej 19, have already been classified as arrowheads by Vang Petersen (1979), whose analysis and frequency seriation of these artefacts classes facilitated the construction of the predominant Scandinavian typology for the Middle and final Mesolithic (1979; 1984). Stationsvej 19 arrowheads have been identified by Brinch Petersen (Pers. Com.). All the projectile points come from sealed deposits and have numbers written on them identifying individual grid references where they were found. All the settlements yielded radiometric data (see next chapter). Osteological data exists for each of the sites below; however, the Danish evidence remains at the Zoological museum in Copenhagen awaiting further analysis and publication. Due to the long history of Mesolithic excavation, all aspects of the assemblages are in varying states of publication.

Four phases from Scania in south western Sweden will provide the osteological data for the case study, as they cover the entire time period of all combined phases, and evidence indicates year round occupation there (see chapter seven). Importantly, the Swedish phases were thoroughly excavated and recently published in a similar manner (Bo Knarrström, pers. comm.); Segebro by Lars Larsson (1982), and the three Tågerup promontory phases under the direction of his students. Per Karsten and Bo Knarrströme directed two phases at SU6 (Karsten 1999; 2001; 2003), and Jessica Mårtensson at SU7 (1999). Lars Larsson's approach is environmental, economic and holistic rather than typological; this common archaeological tradition increases the chance of working with comparable results.

3.7 Kongemose (see figs. 3.6, 3.7)

The Danish type site was found in the summer of 1952 during land reclamation in the large bog area of Aamose in West Zealand. Svend Jørgensen noted the occupation layer seemed to be 25cm thick. The initial drainage work produced many finds, and the initial excavations were backfilled. In 1953 more of the settlement became clear, and Jørgensen attempted to initiate urgent rescue excavations, although flooding in 1954 made this impossible until 1955. Eventually 305m^2 were excavated from a settlement area on the prehistoric lakeside, and a 'rubbish heap' extending into the lake (Jørgensen 1956). 7414 items were recovered from both areas, large blades and blade cores, blade knives/spearheads, scrapers and burins, 'mace-heads', and 50 rough rhombic/asymmetrical axes. Large quantities of organic and osteological remains were found, although the preliminary report was never followed up.

Pollen analysis dated the site to Pollen Zone VI, and five ^{14}C results were obtained, and Jørgensen interpreted the site as part of the 'Early Coast Culture' - a distinctive phase in the continuum between the Maglemose and the Ertebølle (Jørgensen 1956, 39). The largest class of artefact were the c. 2500 oblique arrowheads, although this seems an optimistic estimate, as only half this number is now in the National Museum. Due to the amount requiring analysis, these were not included in Vang Petersen's 1979 thesis, although they have now been classified by Vang Petersen and await publication. Additional continuous variables of weight and thickness were obtained for 934 points during the summer of 2002 at the National Museum, and these are used in chapter five.

3.8 Villingebæk (see figs. 3.8, 3.9)

303m^2 of this Zealand North Eastern site was excavated by Holger Kapel (1969). The character of the finds, rhomboid cross-sectioned flint core axes, long blade technology, and microburin rhomboid *sinister* orientation of arrow heads, suggested a new culture to the excavator. 64 arrowheads were later identified by Vang Petersen (1979, fig. 12). The blade technology was long and thin and produced by a soft hammer technique with an antler fabricator (Vang Petersen 1984, 10, fig. 5). Pollen statistics placed the settlement in zone VI (Jørgensen 1966; Vang Petersen 1979). Seven ^{14}C results were obtained.

3.9 Stationsvej 19 (see figs. 3.10, 3.11)

This 147 m^2 excavation in North East Zealand (Bøttiger-Mørk et al.1999) was part of the wider prehistoric Vedbæk bay project that ran from 1975-1998, through collaboration between the National Museum, Zoological Museum, and the University of Copenhagen. The occupation levels yielded two unpublished ^{14}C results. 75 arrowheads were identified by Erich Brinch Petersen (Pers. Com.). The projectile points are held at University of Copenhagen.

3.10 Månedale (see figs. 3.12, 3.13)

This Northern Eastern Zealand site was found by a river west of Pandehave, and was excavated near the site of Villingebæk Øst A (see above), but remains unpublished. 147 m^2 were excavated. Finds are held at the National Museum of Denmark in Copenhagen. 69 arrow points were identified by Vang Petersen, and the site yielded three ^{14}C results from a sealed stratigraphic context (Sørensen 1996, 170; Peter Vang Petersen 1979, 61, fig. 12).

3.11 Blak II (see figs. 3.14, 3.15)

This submerged coastal site in the Roskilde Fjord on Zealand was discovered 50m from an earlier (but chronologically later) excavation of Blak I and excavated and published by Søren Sørensen of the Færgergården museum (Sørensen 1996, 106). Sørensen produced an accompanying monograph on the Kongemose culture (*ibid.*) which puts the site into a wider geographical context. 137m^2 were excavated, and seven C14 samples were taken. On radiometric and typological grounds, Sørensen chronologically positions this site just after the Final Maglemose, and at the beginning of Kongemose period, in what he calls the 'the Trapeze horizon' Blak phase (see **fig. 3.2**). This supports the theory of a gradual cultural development, rather than a sudden cultural replacement horizon (Sørensen 1996, 5). The 34 projectile points, which consist mainly of broad trapezes, were digitally recorded by scanner and held at the National Museum, so weight and thickness measurements were unavailable for this case study. Although no use ware-analysis has been undertaken, due to a relatively similar shape to the Ertebølle hafted examples, these points may have been transversely hafted; however this would contradict Sørensen's typological interpretation (Sørensen 1996, 56), that follows Van Petersen's 1984 scheme. It is anticipated that the quantitative analyses of the point morphologies undertaken in chapter five may help to resolve this issue.

3.12 Segebro (see figs. 3.16, 3.17)

This Swedish Scanian sight lies on the west bank of the River Sege in Malmö, and was found in 1935 during the laying of a pipe line. Preliminary excavations were undertaken in 1971 and 1973, prior to a major excavation by Larsson in 1976 (Larsson 1982). It has a complex 11 level stratigraphy, and a marine transgression event clearly dating to the second Atlantic Transgression during 4500-4300 BC. A thorough environmental study was undertaken. The occupation levels dated radiometrically from the Late Glacial to the Atlantic. The main period of occupation was from the Atlantic, with finds corresponding to the Early and Middle Kongemose. The find bearing layers are in two stratums, layer 6 was designated the settlement, and layer 7 was the refuse area (Larsson 1982, 129). The prehistoric settlement was situated at the mouth of an estuary allowing a great variety of fauna and flora to be exploited by the local population (Salomonsson 1964). Larsson excavated the site in the 1970's and published it in 1982. The extensive blade technology in phases 6 and 7 of Segebro appeared technically similar to the final Maglemose techniques; differences could be explained by variation in raw materials. The largest class of lithic tools identified were 253 oblique arrow points, and approximately 20% showed evidence of microburin technique. Nine transverse arrows and 23 bone points were found, 8 were slotted. Larsson notes the shape of the transverse arrowheads suggests that they are contemporaneous to the youngest oblique arrows (Larsson 1982, 132). No clear relationship was distinguished by Larsson in point morphology through quantitative analysis of the point continuous variables, other than a remarkable consistency in shape (Larsson 1982, 39). Burins, scrapers, blade knives, borers, and axes, were all identified in large numbers. Nine radiocarbon results were obtained. Organic remains were extensive; charcoal indicated a predominance of prehistoric hazel and oak. Extensive osteological analysis was completed by Lepiksaar (1982), indicating a predominance of cervid remains - red deer, roe deer, and wild boar, in the Kongemose period refuse. Significantly dog bones indicated they were the size of modern elkhounds, and exhibited no signs of cynophagy. Apparently a highly diverse number of species from all local ecosystems were utilised by the population (see chapter seven).

3.13 The Tågerup excavations (see figs. 3.18, 3.19, 3.20, 3.21, 3.22)

Due to the unparalleled extent of the Tågerup excavations, a more detailed introduction is warranted. The three Tågerup phases (SU6 Kongemose, SU7 intermediate, and SU6 Ertebølle; see below), were found situated on a sandy promontory near the confluence of the Saxån and Braån rivers, an area containing a huge Mesolithic settlement that covers an approximate area of 900x500 m^2, with an associated cemetery. Prior to the building of the West Coast Line railway in Scania, the National Heritage Board of Sweden excavated some

20,000 m^2 in one of the largest scale Mesolithic excavations ever, under the directorship of Per Karsten and Bo Knarrström. The main excavations at SU6 was divided into two trenches, East (mainly Kongemose finds), West (Ertebølle finds). SU7 (Intermediate finds) was some 800m away in the innermost area of the former Saxån estuary. Tågerup East was 9,000 m^2, SU7 was 350m^2, and Tågerup West was 14,000 m^2. All excavations were completed over seven months in 1998 (Karsten and Knarrström 2003, 28). 104 radiometric dates were obtained for all the phases, and the results indicated a continuous period of occupation from c. 6500-4800 BC, although there is some evidence to suggest earlier occupation (see next chapter).

In Tågerup, a total of 2.2 tons of flint and rock were excavated from 1,045 squares measuring 0.25m^2, 880 measuring 1m^2, and 119 measuring 4m^2. A variety of classic tool types were found as well as a vast amount of tool variation in the assemblages. Cores, arrowheads, axes, knives, scrapers and burins were found, and extensive use-ware analysis was undertaken to distinguish tool function (Knarrström 2001). Evidence of house floors were distinguished. Tågerup has the oldest cemetery in north-western Europe, whilst many graves are thought to remain unexcavated. In a cemetery found 100m to the east of the Kongemose settlement, six well preserved individuals were buried in five graves, whilst another poorly preserved inhumation from the Ertebølle period was found. These inhumations chronologically spanned the duration of the site (Karsten and Knarrström 2001b, 170). Although in most cases pathology was unclear, a child from an inhumation burial was shot in the pelvis from behind by an arrow. This conforms to a pattern of increasing hostilities in the Northern European Late Mesolithic environment (Karsten and Knarrström 2003, 204).

Most material from the Tågerup excavations is now in the Gastelyckan museum store in Lund. Artefacts were recovered for the current analysis with the help of Magazine staff and the site directors. For the purpose of this study, the material from Tågerup will be divided below into three stratigraphically sealed phases, and will follow the excavators' method of nomenclature. The first phase SU6, will be named Tågerup Kongemose (Tag Kong) the second phase, away from the major excavation SU6, will be called Tågerup Intermediate (SU7), and the third phase, part of phase SU6, will be called Tågerup Ertebølle (Tag Ert).

3.14 Tågerup SU6 – Kongemose (see figs. 3.18, 3.19)

This Swedish site is located on the Tågerup promontory in Scania. A marine transgression event around 5000 BC ensured the excavated settlement area was sealed, and the promontory's geography prevented a restratification of old settlement structures. Little or no evidence of permanent shelters was found in these levels, although osteological evidence suggests year round occupation, according to the excavators, this population may have been more mobile than the later Ertebølle settlement to the East (see below). Extensive environmental and pollen analyses by Regnell (et al. 2001, 256), revealed woodland consisting of elm (*Ulmus glabra*), pine (*Pinus sylvestris*), lime (*Tilia cordata*), oak (*Quercus robur*), and besides the wetlands, Alder (*Alnus glutinosa*), Birch (*Betula pendula*), and various willow species (*Salicaceae sp.*). Pollen indicates the crowns of the trees formed a cover of foliage that allowed only sparse understory, whilst riverside environments provided many more species (Karsten and Knarrström 2003, 35).

234,168 units of worked flint were found in the Kongemose levels, comprising 20,000 relatively long blades, 10,000 microblades, and a total of 179, 815 flake pieces. 20% of flint was diagnostic of an elegant long blade technology that consisted of projectile points, cutting and scraping tools, and 570 blade burins. 252 complex blade cores were recovered and clearly prepared for long blade separation by a type of bifacial technique (Bordes and Crabtree 1969; Biagi and Cremaschi 1991), whilst 691 simple polygonal blade cores were found, and these would produce simple flakes. Small pointed-oval striking platforms characterised the long blades, whist 95% of all blades and blade fragments with preserved proximal ends showed morphological evidence of an indirect punching technique, indicating a tradition continued from late Maglemose and early Kongemose Blak phases (Larsson 1978; Sorensen 1996, 78). Two antler tines related to this method of flint knapping were recovered (Karsten and Knarrström 2003, 39). The lithic industry indicates a period of manufacturing excellence, mainly higher quality Scanian Senoian flint was used for blade cores and blades, obtained away from the vicinity of the settlement.

A total 911 arrowheads were identified, consisted of 535 trapezoid microliths, 282 oblique or rhomboid microliths, and 28 oblique transverse arrowheads of varying shapes and sizes (Karsten and Knarrström 2003, 59; see chapter five). A tiny proportion of other points were found, 30 straight-bone and slotted-bone points with microlith inserts and point prefabricates were recovered, usually made from shin bones and metatarsals of deer. These points are possibly 'bleeders', to open a large wound channel best shot from a bow at close range to the prey (Karsten and Knarrström 2003, 65). Although early interpretations suppose these points were from 'bird arrows', this is unlikely according to ethnographic sources (Ellis 1997). Instead, the scarcity of bone points may indicate a prestige value. They generally require longer manufacturing time, and compared with the microlith points have stark difference in size, shape, and material indicative of a prey specific point, possibly even war points, as they resemble medieval metal broad-heads to a degree (see previous chapter).

37 wooden artefacts were recovered, as organic material was retrieved from anaerobic levels. Wood, bone, plant macrofossil and pollen evidence was analysed. Evidence of stakes and poles indicated abutments for bridges and moorings on the ancient coast. The Kongemose finds were designated as 'Phase I' by the osteologists Eriksson and Magnell (2001, 212), and the osteological seasonal indicators suggested year round occupation. 23,857 units of osteological material were found, mainly evidence of waste from hunting strategies, with a bias towards large ungulates (see chapter six). Much of the osteological waste was found away from the main settlement area. Evidence from red deer (*Cervus elaphus*) indicates only 2-5 year olds and individuals 10 years were selected, when antlers initially develop and antler development begins to recede, respectively. Other prey included roe deer and wild boar, although no clear patterning of prey-selection emerged here (Karsten and Knarrström 2003, 68). Marine animals were likely hunted out in the Sound; seals were probably clubbed after being driven inland, although seals and small whales could be hunted with leisters and net traps (Karsten and Knarrström 2003, 70). Dog teeth (*Canis familiris*) are found in the early Kongemose levels, but are less prevalent later on. The role of the dog in bow hunting, either by baying, beating, or tracking may have been key to the majority of pre-historic bow-hunting strategies.

3.15 Tågerup SU7 – Intermediate (see figs. 3.21, 3.22)

This site was excavated in 1998-1999 and is situated 800m east of the Tågerup promontory (Mårtensson 1999). It was located in a prehistoric wetland area adjacent to a brook flowing into the bay. The site area was slightly higher than SU6 at 3.5 - 4m above sea level and roughly 100m^2, inclusive of terrestrial settlement and wetland refuse area.

The material is difficult to classify using extant typology. 90% of the 1,697 blades were made by indirect technique. A difference in raw material is evident between indirect blades that also exhibit a greater degree of patina, and blades produced by hammerstone techniques. Seen in conjunction with dates that apparently fall into the early Ertebølle period, this is interpreted as two different occupation horizons by Karsten and Knarrström (2003, 132). 61 arrowheads were identified, and were classified into three roughly equal groups, big oblique transverse, straight edged transverse, small oblique transverse shapes, and a rhombic flake. However, a great deal of morphological variation is evident. Over 4 kg of bones were excavated, and 54% have since been identified, and are seen as having a similar composition to the Ertebølle assemblage. The finds from this area were designated 'Phase II' by the osteologists, and as with Phase I above and Phase III below, the seasonal indicators suggested year-round occupation (Eriksson and Magnell 2001, 212).

3.16 Tågerup SU6 – Ertebølle (see figs. 3.18, 3.20)

Marine transgression meant the Ertebølle coastal settlement dates to around 5300 BC and was between 3 and 4.5 metres above sea level, and further inland than today, and to the east of the Kongemose settlement, on the contemporaneous shoreline. The Phase III Ertebølle settlement in the east of the site area is clearly larger than the Kongemose in the west (Karsten and Knarrström 2001, 171). The flora was similar to that of the Kongemose period, with elm, lime oak and birch, despite a generally wetter climate (Liljegren and Lageråsi 1996; Karsten and Knarrström 2003, 138). Post holes indicate dwellings were of considerable size, including two circular houses, a long-house and a windbreak. Use of wood increases dramatically as more timbers were used for buildings, fish traps, heating and cooking, for a larger population. This probably prompted small scale clearance of land for very limited cultivation, in a kind of basic woodland gardening. Coppicing apparently occurred in this period, and has been determined through evidence of ring barking, a procedure used to kill the crown of the tree to promote bushes, herbs, and grasses (Mårtensson 2001: 295). The possibility of this type of woodland clearance is also indicated by the pollen of species present, such as fat hen (*Chenopodium album*), common sorrel (*Rumex acetosa*), wild cherry (*Prunus avium*), elder (*Sambucus nigra*), and blackthorn (*Prunus spinosa*) among others (Karsten and Knarrström 2003, 138).

In contrast to the Kongemose levels, Ertebølle waste was thrown away on land beside the dwellings (Eriksson and Magnell 2001, 185). 83 wooden artefacts were recovered, Fish traps, poles and stakes covered the promontory. Remarkably, a largely intact wood/antler composite indirect pressure flaking tool was retrieved from the site, also some rare composite slotted arrow heads, fragments of arrow shafts, and a decorated polished axe handle (Karsten and Knarrström 1998; 2003, 83, 146).

219,834 pieces of worked flint were found in Ertebølle contexts, with only 0.2% being formal tools, although expedient use of debitage for cutting and scraping is likely. The flint assemblage comprises of simple hard percussion flint flakes, with a tiny proportion using a softer technique. Local flint sources, mainly moraine deposits, were used despite evidence of other sources away from the settlement. This procurement strategy is also found at Skateholm and elsewhere in Scania (Larsson 1988, 75; Karsten and Knarrström 2001, 105). 4,141 blades were found, and were produced from largely unprepared platform cores from 'sausage flint' nodules.

14,370 osteological units were found. Large ungulate species were the central focus of the subsistence strategies; however, this period had an increase in the different types of animals, notably small fur bearing mammals indicating the possibility of increased trade. The finds from this area were designated 'Phase II' by the osteologists; the seasonal indicators suggested year-round occupation (Eriksson and Magnell 2001, 212).

Chapter 4: Case study chronology

4.1 Introduction.

This chapter orders the find-bearing levels of the Southern Scandinavian case study into a time-step series in terms of available ^{14}C data. This creates a chronological model where archaeological assemblages can then be compared at the same scale, independent of relative dating techniques. Previous South Scandinavian chronological models are analysed, problems with relative dating methods that use point typologies are explained.

The case study chronological methodology using the OxCal calibration program is now detailed (Bronk Ramsey 2002). The OxCal method presented below was developed after many lengthy discussions with John Meadows at the Institute of Archaeology, University College London, during the summer of 2003. However, John's generous advice was not always followed, and all methodological problems and errors are entirely the fault of the author. Where specific OxCal terminology is involved, the commands are placed in bold type e.g., **Phase,** as precise mathematical definition of these terms is not always the same as those used in common archaeological parlance. An absolute chronological model for the case study site-phases is formulated, in terms of start and end boundary distributions, and phase duration. This gives a tailor-made chronological framework for the analysis of assemblage variation in the following two chapters. This chronology accounts for duration and span of the case-study point-bearing levels in terms of available radiometric data and stratigraphic information, allowing parallel examination of the osteological data in conjunction with contemporaneous lithic technology (see next chapter).

The Middle Mesolithic period in South Scandinavia has the earliest known stratified arrowhead evidence, with statistically significant sample sizes, that could be ordered using absolute dates. The data available for the case study sites indicated great potential for the Bayesian ordering of find-bearing phases using OxCal modelling procedures (see below). The method and results presented here utilise the many radiocarbon dates from the stratigraphic levels yielding projectile point data from the nine available phases in Zealand and Scania, as introduced in the previous chapter. OxCal's modelling facilities have been used to order the roughly contemporaneous sites' projectile point bearing phases, by calculating the probability distributions of the dates of the phase boundaries (start and end) for each site, and the probable sequence of these dates. A series of confidence ranges is calculated in calendar years. This process explicitly quantifies the probability of certain projectile point bearing phases occurring before others, enabling the creation of a time step series in calibrated calendar years (see below). The probability distributions, given the available data, of start and end dates for each of the eight site phases are calculated by using the **Boundary** function. The probability distribution of the length of site occupation (each phase's total span in calendar years), is calculated by using the **Span** function. The quality and quantity of dates and stratigraphic contexts available in this region allows an unusually fine grained geographic and temporal resolution. The method presented is more akin to the recent Upper Palaeolithic reoccupation study of Blackwell and Buck (2003), although their study had less complexity, fewer dates, considerably greater geographical coverage, and much less stratigraphic context integrated than the case presented below.

4.2 Southern Scandinavian Middle Mesolithic chronological issues

The long and distinguished Scandinavian history of typological dating originating in the case study region has been discussed in chapter three. The predominant approach to projectile-related chronological interpretation here, relies on typological frequency seriation. Vang Petersen's method measures morphological elements of the quadrilateral microlith arrowhead, including an internal angle of the leading edge (v), and the sinistral or dextral orientation of the point as shown in **fig. 4.1** (Vang Petersen 1979; Vang Petersen 1984; see next chapter). The relative percentage of point types from other stratigraphically sealed phases are then seriated into 'battleship' curves, relative to percentages of other classes of artefacts. When a unimodal distribution has been obtained, a homologous lineage is assumed, which is then subdivided into presumed chronologically sensitive arrowhead types.

The resultant arrowhead typology has been canonised by a general correlation with other ^{14}C dated archaeological phases from (Danish) type sites (see below, Vang Petersen 1979, fig. 64). For instance, Villingebæk phase arrowheads are characterised by a sinistral orientation and a certain combination of continuous variable ratios, where the internal long diagonal (a) and short diagonal (b) have a ratio of ($a{:}b \geq 1.5$), with straight basal retouch and broad edge (c) ration of ($a{:}c < 1.75$). Vang Petersen cross referenced this with ^{14}C

distributions from the sites in question, so logically he divided the resultant phases up into essential arrowhead types (O'Brien and Lyman 2000). This typology gave a plausible date range to similarly shaped points in the region, where more securely dated archaeological context is unknown. Percentages of arrow head types are calculated for each phase, and then the relative percentages are ordered into normally distributed battle-ship shaped curves, and compared with other battleship curves derived from percentage frequencies of other artefact classes. This follows the same principles as Kroeber's original method concerning Zuñi pot sherds (Kroeber 1916; O'Brien and Lyman 2000, 291).

Following Cowgill, a seriation has two aims, firstly to determine the correct order of a group of archaeological units, and secondly to order these units according to their similarity (Cowgill 1968, 517). Whether these units have a chronological ordering is not predestined (O'Brien and Lyman 2000, 296). To produce a technological homologous lineage, frequency seriation has to fulfil several criteria (Lipo et al. 1997; O'Brien and Lyman 2000, 81). These are;

1. A similar geographical sphere of population/group interaction
2. A gradual evolutionary development of the traits in a class of artefact
3. No technological convergence

Independent technological invention, or technological convergence outside of the evolutionary sequence, falsifies a frequency distribution scheme - similar to the criticism Julian Steward made of the 'age-area' concept in 1929 (see chapter two). If the frequency seriation criteria are not met, the typologically derived temporal sequence extrapolated from the seriation is wrong, and requires re-evaluation.

Although accepted in Denmark, chronological problems have arisen when Vang Petersen's Danish typological method is used to determine settlement occupation dates in Swedish contexts, less than 100 km away. Recently, a functional use-ware study by Knarrström (Karsten and Knarrström 2003) determined that rhombic arrow-heads from the earliest phases of the Scanian Tågerup excavations, were not obliquely hafted. These early Tågerup points were radiometrically contemporaneous, if not earlier than Blak II phases in Zealand. In contrast, Sørensen (1996, 107) assumed an oblique hafting method for Danish Blak II

Rhombic microliths. His radiometric dates were earlier than the Villingebæk dates, so this seemed a logical assumption assuming a gradual lineage of bow-arrow point-hafting traditions. Sørensen (see **fig. 3.2**) agrees with Vang Petersen's (see **fig. 3.5**; 1999) and Fischer's (1997, 80; see **fig 3.4**) typological sequence, and assumes a gradual change from obliquely hafted points from the Maglemose, Blak, Villingebæk, and Vedbæk phases, through to the Early Ertebølle phases of Trylleskov, changing to fully transversely hafted arrowheads in the Middle Ertebølle Stationsvej phase (Vang Petersen 1984, 10-11). Without published use wear analysis of the hafting element of the Blak phase points, which could demonstrate hafting orientation through examination of microscopic wood polish, and haft-element impact fractures, this problem cannot be satisfactorily resolved qualitatively, as the Blak II points were not incorporated into Vang Petersen's original seriation scheme, as the site was unexcavated. If the results of the functional analysis could be incorporated into the scheme, it would be more convincing. At present this typological issue requires further investigation. A quantitative analysis of point shape demonstrates further problems with oblique hafting interpretations of these early Kongemose phase points (see chapter five).

In theoretical terms Vang Petersen's approach compares the relative frequency of certain attributes supposedly time sensitive and assumed to be unimodally distributed. Lipo is explicit about the inadequacy of frequency seriation when used atheoretically in this manner (Lipo 1997). Frequency seriation is often used as a probabilistic technique to shuffle assemblages until the best fit to a unimodal curve is achieved, which is then blindly taken as chronologically sensitive. However, an order will always be produced by the associated program-algorithm, despite the possible use of inappropriate units of analysis. This encourages assignment of spurious ethnonyms to arbitrary groups created by the seriation (see **fig. 3.2**; O'Brien and Lyman 2000, 296, 297). To fit the theoretical requirements for seriation, theoretical unit sequences have to be compared like for like, with a similar class-phase time duration; this proves to be a key problem with Vang Petersen's typological method (see below, and next chapter). Chronological and technological inferences drawn from samples taken from short duration or unevenly distributed phases durations will consequently be shaky, as they fail to meet the required frequency seriation criteria (O'Brien and Lyman 2000, 296). More subtle cultural group divisions may be required, that account for different modes and tempos of technological transmission than is traditionally assumed (Bettinger & Eerkens 1999).

To avoid compounding further essentialist/relative dating problems (O'Brien and Lyman 2000), a radically different approach is taken here, where a time-step series solely based on absolutely dated point-bearing phases is used. This is constructed for the nine point-bearing phases used in this study. Bayesian statistical methods are employed to order the nine phases, giving them their most probable start, end, and site span dates in calibrated calendar years -strictly in terms of the available stratigraphic information and extant ^{14}C data.

4.3 Bayesian Method

Radiometric dating is a probabilistic enterprise which can benefit from a Bayesian approach (Bronk Ramsey 1994; 1998; Buck et al. 1994; 1996). Bayesian statistics deals more explicitly with ^{14}C probability distributions than classical statistics in certain circumstances. Models are built to explicitly account for one's initial strength of belief in a hypothesis, by expressing this belief as a series of alternative possibilities, based upon reasonable expectations. Data is introduced into the model, new probabilities are calculated and as a result the initial strength of belief concerning the alternative possibilities is refined. Data and inference are better integrated than previous classical models, although prior probabilities are often difficult to account for, and require case by case consideration (Shennan 1988, 48-49). Recent increases in computer power enable Bayesian inspired algorithms to be incorporated into widely available statistical programs to analyse archaeological data. The precise mathematics are beyond the scope of this chapter; however, Buck et al. (1994; 1996) note that in contrast to classical statistics, a Bayesian approach is one which uses probability as a means of measuring the level of confidence that one has in a particular model or hypothesis being true. It is a method that is conditional on both the information provided by - and the interpretation of - the architect of the particular model in question. It is an approach ideally suited to help interpret and clarify patterns of archaeological data.

This is not the case with classical box plots of carbon dates, for instance Sørensen's (1996) absolute dating graph for the Kongemosen period in the Middle Mesolithic of south Scandinavia (see **fig. 4.2**). They do not represent carbon dated events as the conditional probability distributions they actually are. Samples do, or should, date single events, whilst the error range on a box plot looks like a period - not an event - whether or not it is calibrated. Unfortunately, the usual way of presenting radiometric data in archaeological reports reinforces a misleading view of results as definite single events within a definite unimodal error range. The classical approach of representing ^{14}C samples only reinforces typological and culture historical assumptions. As well as being potentially misleading, these approaches fail to maximise the potential that a Bayesian analysis can yield (Buck et al. 1994). In contrast, the Bayesian approach offers a rigorous methodology for presentation and ordering of calibrated radiometric data. Some potential for modelling complex relationships between cultural occupation horizons is now being realised, for instance in studying the post glacial resettlement of Europe, albeit on a broad geographical scale, with a comparatively small number of ^{14}C plots (Blackwell and Buck 2003).

If vagaries of sample collection and calibration curve remain unaccounted for, problems of interpretation will follow. As Waterbolk stated, the final graphic representation has to account for individual characteristics of the separate ^{14}C events (Waterbolk 1983).

Isotope decay curves are used to obtain the uncalibrated ^{14}C distribution result. The calibration curve relates the radiocarbon years to calendar years by radiocarbon dating wood samples (dendro-dating) of known calendar age. The atmospheric decay curve used by OxCal is INTCAL 98 (Stuiver et al. 1998). Luckily the curve is helpful for the case study period; that is to say, the curve slopes down in a relatively even way that should not present too many confusing results. A really difficult part of the curve is fortunately just before the period of this study, where there is virtually a straight line around 8000 BP radiocarbon years. Radiocarbon determinations hitting this part of the curve would be highly problematic.

It has been suggested that the uniform distribution rate of material in an archaeological phase may not be the appropriate distribution to use, and that it should be more of a trapezium shape - a non-uniform distribution to account for the probable sparseness of data, and a less likely deposition of radiometric events in early stages of a reoccupation horizon (Blackwell and Buck 2003). At any rate, traditional plot representations of ^{14}C results, namely Sørensen's (1996 see above) are potentially misleading. These problems are compounded if you compare more than one radiocarbon result, without accounting for each sample's individual probability distribution against the calibration curve. If sample results are presented together in classical bar chart form without careful qualification, many culture historical assumptions are wrongly reinforced. Calibration programs incorporating Bayes inspired sampling algorithms can help circumvent this problem - provided that the radiocarbon ages are not themselves misleading.

4.4 Archaeological considerations concerning radiocarbon samples

Prior to the analysis of radiometric results, a number of archaeological problems need to be accounted for (Waterbolk 1983; van Strydonck et al. 1998; Pettitt et al. 2003). The archaeologist taking the original sample has to be convinced that it is representative of the stratigraphic phase it is associated with, and not likely to be intrusive due to taphonomic process. Each sample to be lab-processed has to fit certain stringent criteria, or its age and context related associations with a certain archaeological phase will be wrong (Buck et al. 1994). Sample source type is crucial. Other than the possibility of sample contamination during excavation, or problems during the processing in a particular laboratory, it follows that a sampled small twig is better than a sample from heart wood, as, all being equal, the former is more likely to be closer to the actual event or context date required, due to its shorter life span. This principle affects the validity of all samples in a model.

4.5 Offsets

Sometimes it may be tempting to discard a sample that seems very erroneous from a report - even when these occur for purely statistical reasons, for instance, with a 95% confidence level in a series of samples' age, one in 20 samples could well be statistical outliers. These should be included in the results. Other samples may produce unexpected results, which are not at all surprising on closer investigation of the original type of sample material. For example, rather than disregarding an awkward sample's radiocarbon result, some interpretive problems can be avoided by explicitly offsetting any intrinsic age, using the **offset** command function in OxCal, specifying a certain number of years to safely account for the particular problem, such as the short-lived twig versus a potentially long-lived heartwood sample. The analysis can then be run with and without offsets to determine if, and how, the final results were affected by the suspect samples.

Another problem is that of human bone. When a marine resource based diet is predominant as opposed to a predominantly terrestrial diet, human bones absorb carbon from the marine reservoir which has an apparent radiocarbon age of several centuries. The reservoir age varies according to location but is ca. 400 radiocarbon years on the Danish coast. This affects the appropriate type of calibration curve that should be chosen for result calibration, and raises the question of whether or not a sample should be included in the archaeological analysis if it is likely to confuse interpretation. There are only a few samples of human bone used in the case-study data, so this is not considered a major problem.

In summary, given the aggregate of available samples that are to be taken as representative of a given occupation phase horizon, which may have a range of dispersed results when calibrated, the probabilistic nature of the dated events has to be fully accounted for prior to final interpretation. In short, the Bayesian methodology incorporated into the OxCal package provides the necessary statistical rigour for an accurate comparative analysis of the archaeological data in this case study.

4.6 Case-study OxCal method

The Bayesian method presented here will order the aggregate absolute dates of each case study phase, to enable comparison of point and environmental variation through time. Before a discussion of each phase's radiometric data and context, an understanding of how the calibration program works is necessary. OxCal uses a combination of the Metropolis-Hastings algorithm and the Gibbs sampler, to perform Markov Chain Monte Carlo (MCMC) sampling to generate the best fit posterior probability distributions, which are compared to the prior probability distributions - the calibrated radiocarbon results. A total of 30,000 iterations were made for each run of the model used in the case study (see below). OxCal then gives an agreement index indicating the internal statistical consistency of the final model produced. This index of agreements is not a chi-test statistic, but the threshold 60% value is analogous to the 0.05 significance level of a chi-squared test. Bronk Ramsey warns that if the overall agreement index in the model drops below 60%, it may be due to the inclusion of residual or intrusive samples in the stratum (Bronk Ramsey 2002).

Extensive absolute dating in this Southern Scandinavian case study region, with 200+ Radiometric dates from the end of the last Ice Age c.10, 000 BP, to the end of the Tågerup Ertebølle Phase c. 6500 BP, allows construction of a series of linked OxCal generated chronological models. Superimposed phase boundaries defined by the archaeologist's skill at interpreting archaeological stratigraphy are incorporated into the final model, as it is constructed in the form of a Harris matrix.

4.7 The case-study model

The way in which the final OxCal model is arrived at for the region will now be explained prior to a necessary discussion of each site's radiometric data, and results. A number of methods was attempted prior to the final model. These included visual analysis of each radiometric date distribution and combining all the results before and after calibration (using **R_Combine** and **Sum** functions), before the final integrated case-study model was arrived at. This method calculates the dates of phase boundaries, the likely order of dates, and the duration of each phase using a combination of **Phase**, **Boundary**, **Order**, **Span** and **X_Reference** functions (see below).

Please note that in the final chronological model, the occupation phases are represented each by a single site. This results in a falsifiable hypothesis and is not necessarily a highly robust demonstration of regional patterning using a larger, multi-site dataset. However, the Bayesian method is used here solely for the purpose of accurately *sequencing* the projectile point data, to enable other ecological data to be synchronously compared. Also, prior to the construction of the final chronological phase model, multiple models were run both with and without older bulk samples, and with and without 'problematic' outlying samples – as detailed below, on a phase by phase basis. The results from these multiple preliminary models showed that the chronological time-step ordering used in the final analysis was as accurate as possible given all the available radiometric and stratigraphic data.

Each sample used was examined for potential problems following Waterbolk's guidelines (see above). The data set was checked for each site, and recorded in Excel. When a data sample is rejected, a question mark is left against it in the OxCal phase model, to allow visual comparison of the probability distribution with other samples, but without its inclusion in the overall analysis. Any instances of radiometric data exclusion are explained below. The data was then transferred into OxCal, and calibrated on a site by site basis. Each site's data was calibrated against the INTCAL 98 calibration curve (Stuiver et al. 1998). Problematic samples and outliers were examined further, to see whether there were any particular sampling problems that could be accounted for, as mentioned in the previous section. Each sites' data will be discussed separately in no particular chronological order, prior to a total summary of the data, before results from the final chronological model for the region are explained.

4.8 Data preparation

The final integrated **Phase** and **Boundary** model was arrived at after comparing two final runs of the program, one with as much radiometric data as possible, and the other with just the data coming out of the point bearing stratigraphic levels. The aim is to be as inclusive as possible with the data to provide as much prior information as possible, however problematic samples must be accounted for and removed from the analysis if necessary if the final model is to be meaningful.

Prior to the final time-step model decision, the radiometric determinations from each site require discussion in terms of stratigraphic contexts, sample types, and individual anomalies. Each set of radiometric determinations are discussed and entered into OxCal as an unordered **Phase.** In OxCal, a **Phase** is an unordered group of results, that assumes there is no *a priori* knowledge that any sample is older or more recent than any other. Calibrated distribution **Boundaries** were created by running the program. In OxCal the probability spread of a **Boundary** is determined by the distance between the ^{14}C results - the boundaries would be wider apart if the phase lasted longer. This allowed an ordering of start and finish **Boundary** distributions for each site **Phase** in relation to the others in the case study.

For the sake of transparency, all available published, and in some cases unpublished radiometric sample data from all the case-study site-occupation phases have been included in the final phase model - and referenced in **tables 4.1 to 4.9**. The following section is a detailed discussion of this data as it is contextualised on a phase by phase basis, and details precisely how 'problematic' dates were dealt with prior to construction of the final chronological phase model for the case-study occupation levels. When the results of running the model presented a low individual sample, and/or a low overall model agreement index, i.e., a result presenting below 60% level in agreement, the sample itself was examined again, to see if there may have been a problem in the sample type (e.g., data extrapolated from a bulk sample from a trunk rather than an AMS result taken from a twig, see below). All related problems are detailed below on a site phase by phase basis. If the result was obviously dubious, the reasons are detailed below, and these dates were **questioned** in the final run of the OxCal model. The OxCal **question** function was used to ensure that the potentially available data was clearly visible to the observer, for the sake of transparency, whilst it was not included as part of the final analysis run of the OxCal phase model. This final phase OxCal model is shown in the accompanying **Appendix CD**, and is named **ch4_phasemodel_14**. Data with a question mark next to it, i.e., result Tag Ua-9938 is therefore shown in the **phase Tåg Ert**, but is not processed by OxCal in the final chronological model, for reasons explained below.

In an attempt to constrain the length of the chronological phases and their respective start and end probability distributions as much as possible (see **fig 4.12**), radiometric results from sealed stratigraphic contexts known to chronologically bracket the main occupation layer phase were also used in the final chronological model; see **Appendix CD ch4_phasemodel**. These bracketing results can act as a terminus ante quem **(TAQ)** and a terminus post quem **(TPQ)** for the main occupation phases, because an OxCal phase model, if so instructed, can incorporate this useful prior knowledge. This is clearly seen in the case of the Segebro phase shown in the **Appendix CD ch4_phasemodel**. Even radiocarbon results extrapolated from bulk samples of peat - as in the case of the Kongemose phase data - may help to provide a more accurate final model. However, it is acknowledged that running the models without these results may in some cases provide a different chronological phase start/end distribution than presented here, and that bulk samples taken in the 1950's are not ideal for this purpose. Please note that **TAQ**'s and **TPQ**'s were always used here when available, and that multiple models were generated with and without these constraints, to compare the results. It was found that using **TAQ**'s and **TPQ**'s can help tighten the final phase model date ranges considerably, without significantly altering the final site phase start-end chronological orderings. However, it must be underlined that this may not always be the case for future case studies made elsewhere, as Bayesian analysis of data carried out in this manner must be made on a case by case basis.

The following section will discuss the context of the radiometric samples, then the data entered into a phase model for the individual site for calibration prior to consistency checks using the OxCal agreement index, so outlier result distributions can be removed or accounted for, in the final model. The ^{14}C results were taken from the following reports, Brinch Petersen 1975; Karsten & Knarrström 2001; Larsson 1982; Sørensen 1996. There are over 200 ^{14}C results available from the traditionally termed Kongemosen and associated Late Maglemosen sites (Sørensen 1996, 172-176), although the 102 dates finally used below are unevenly distributed across the case study sites. All the following phase models can be found in the **Appendix CD**, in the **Appendix CD ch4.phasemodel.14i**.

4.9 Kongemosen radiometric data (see tab. 4.1)

This is the type site for the culture historical horizon in question, and has five radiometric results available for analysis. Samples K-1527 and K-1526 come from the swamp peat immediately above and below the cultural layer, and were taken as representative as *terminus ante quem* (**TAQ**) and *terminus post quem* (**TPQ**) for the occupation horizon bearing the projectile points. Reliability of radiocarbon results extracted from the bulk samples of peat was anticipated as poor, given composite nature of samples. The three other samples are taken from one hazelnut and two tree bark samples respectively, and are therefore considered as relatively good representatives for the occupation horizon, assuming no post-depositional movement. Sample K-1589 comes from the refuse layer and could possibly be anomalous, were it not considered synchronous with the settlement layer on stratigraphic grounds where the other samples were extracted (Jørgensen 1956; Vang Petersen, Pers. Com.). When all the Kongemose results were calibrated in OxCal as a sequence with boundaries, the overall agreement consistency index was high at 95% for the model, and as the two samples K-1527 and K-1526 from above and below the cultural horizon levels tested as consistent at 99.9% and 98.6% respectively, they were accepted for final analysis.

4.10 Villingebæk Øst A radiometric data (see tab. 4.2)

There are seven radiometric results available for analysis (Kapel 1969), all from the occupation horizon. Sample K-1368 is the only sample from charcoal, the others are from a variety of wood sources including a fish-trap (K-1486). The initial bounded sequence was run, and had a relatively large +- error range of 120 compared with the other case study samples, the resultant confidence levels were very high, with an overall agreement index of 121.9%, with steep well defined boundaries. Larger error terms increase the index of agreement because the data is less constrained; this is reflected by the results being over

100%. There was no inherent problem with the fish-trap sample, as the marine reservoir effect only affects samples originally from a marine environment, or with a marine diet such as sea birds or humans. All samples were accepted for the final analysis.

4.11 Månedale radiometric data (see tab. 4.3)

This unpublished site has three dates available. All samples were charcoal, two were from the settlement layer and one from a pit (K-1827). The pit sample could be problematic if it cut though the settlement layers and was not contemporaneous to the rest of the settlement, this could potentially skew chronological interpretation of the projectile point bearing level. Analysis of the stratigraphic profile placed this sample as below the culture layer, and probably older (Vang Petersen 1979, Profile 4). The initial all inclusive program run agreed with this interpretation, and passed the agreement test at 94.3%, so all three results were accepted.

4.12 Stationsvej 19 radiometric data (ST19; see tab. 4.4)

This phase yielded potentially problematic samples as only two are published (K-4714 and K-4959), from the culture layers (Sørensen 1996), These agreed at a total for the sequence at 93.7%, however OxCal could not reject one of only two results in a model, and due to the small sample size the boundaries created were very widely distributed and may not be much use for the final time step analysis.

4.13 Blak II radiometric data (see tab. 4.5)

This submerged site in the Roskilde Fjord in Zealand (Sørensen 1996) yielded seven ^{14}C dates. Intact parts of submerged Mesolithic settlements such as the Blak II phase are not uncommon. The extensive survey and excavations in the Danish Storebælt recently revealed many settlements underwater, e.g., in the Musholm Bay, that yielded Fischer's Type 'M' 'Blak' Phase points (Pedersen et al. 1997, 80) that the excavators roughly dated to 7800 – 7600 BP, by comparing four ^{14}C dates. Nonetheless the Blak II phase is particularly important to date accurately, as it supposedly yielded the earliest obliquely hafted points from the 'Trapeze horizon', which is an area of great archaeological contention in Scandinavia (see previous chapter). Being a submerged site, much use was made of the tree stumps from trees that died from immersion in saltwater to date littoral transgression horizons after the last ice age (Pedersen et al. 1997). However, problems in dating can sometimes result if the wrong calibration curve is selected, due to different rates of ^{14}C absorption in terrestrial and littoral contexts. This problem may affect the Blak II human bone sample, found in the culture layer (Ka-6454). Without knowledge of the species that bone (K-5836) came from, i.e. whether it has a terrestrial or marine diet, it is impossible to determine the appropriate calibration curve or combination of calibration to be used (see above).

The wood samples stopped absorbing ^{14}C when the tree died, and were quickly covered in protective layers of silt and sediment. Therefore, if there are similarly stratified levels of trees either side of a settlement deposit, and settlement deposits and trees are covered and left undisturbed since abandonment in the same stratum, we have access to potentially accurate date-range of site occupation. However, this is assuming the samples taken were from the youngest available part of the tree when it died, e.g., a root tip (K-5835), and sapwood from the stump (K-5663), as in the case of Blak II. An OxCal **Offset** can still be applied to stump samples to test the effect of date offsets and program runs with and without bone samples included, to examine the validity of different runs with combinations of bone samples included. The first run was a sequence with all available dates included, and although there was an overall agreement of 79.1% the non-human bone sample failed the 60% internal agreement index test (K-5836 at 1.6 %). The human bone sample (Ka-6454) passed at 94.3%. The very low agreement of K-5836 may indicate it being an intrusive sample into the group, possibly resultant from taphonomic process, although it is acceptable at the 54.2% run, as it is the overall index that is more important. A run without the non-human bone sample, passed the overall agreement test at 91.8%, so this was accepted for the final analysis.

4.14 Segebro radiometric data (see tab. 4.6)

Segebro presents some problems stratigraphically, in that it is necessary to create a sequence that encompasses all the associated point material coming from two abutting artefact bearing cultural phases, layers 6 and 7. One additional sample comes from culture bearing layer 5, from a *lergyttja* or 'sludge-layer', with the same distribution as level 7 - and overlaying it. Layer 5 abuts the culture bearing sandy layers 6 and 7. Layers 6 and 7 are representative of a single stratigraphically sealed settlement area and refuse area, which was originally divided into two levels by Larsson as they produced characteristically separate groups of finds (Larsson 1982). To complicate matters there is another available ^{14}C distribution available (St-812) from a yellow sandy layer 10 bordering the cultural layer (Larsson 1982). The first run of the OxCal sequence, including all nine available dates failed the agreement test at 56.7%. Sample St-812 from level 10 was the most problematic at 20% and clearly out of the sequence, as suspected on stratigraphic grounds.

Sample St-812 was therefore considered a statistical outlier not relevant to the duration of the occupation phase, and was not included in the final run of the OxCal phase analysis.

The second run of the sequence excluded the level 10 sample St-812, and was a combination of levels 5, 6, and 7, which represented all the ^{14}C samples available for the point bearing levels. This passed at 96.8% and was accepted for the final analysis. The final run incorporated Layer five as a *terminus ante quem* (**TAQ**), and Layer 10 as a *terminus post quem* (**TPQ**) for the find bearing layers. This enabled steeper start and end probability distributions to be obtained from the data; this method produced an agreement index of 105.9%.

4.15 Tågerup Kongemose radiometric data (Tåg Kong; see tabs. 4.7A, 4.7B)

The 59 ^{14}C results taken from the Kongemosen phase layer 4 of the excavation are used (Karsten and Knarrström 2001, 233). The radiometric distributions were taken from the animal osteological material (although some human ^{14}C dates were used), and from the wood samples. The samples were taken from a find bearing level, 4, and from the two grave contexts attributed to the Kongemosen on stratigraphic grounds (Karsten and Knarrström 2001). The initial sequence run with all the distributions passed at 85.1 %. After the initial run, two problematic samples were deducted from the analysis; Tag-Ua-25206 at 50.9% from a grey seal (*Haliochoerus grypus*) cranium, and Tag-Ua-25470 at 56.9% from a charcoal sample from grave 1 fill, both failed the agreement test. The new sequence was run, and Tag-Ua-25191 from level 6, an Astragalus bone from wild pig (*Sus scrofa)* and (Tag-Ua-25193) from a femur of wild pig failed the agreement test. These samples were removed and the final run agreed at 111%, with much higher and tighter distributed peaks. The charcoal sample could be explained as debris from a latter fill, whilst the others samples could be put down simply to taphonomic incursion, or lab error - even a 95% confidence interval would naturally generate 5 outliers from a sample of 100 dates. As the pig bones were more than two thousand years away from the mean age (and two standard deviations is only 200 years), these samples look highly intrusive. However, all runs produced very similar sharp start/end boundaries with very short probability distributions due to the large number of ^{14}C results used, so there was little effective difference between the runs.

4.16 Tågerup Ertebølle radiometric data (Tåg Ert; see tab. 4.8)

A total of 17 ^{14}C results were obtained from layer 6, primarily from animal bone and wood finds, covering the duration of the Ertebølle cultural division in the Tågerup Excavation (Karsten and Knarrströme 2001, 233, 283). Ua-9938 from red deer antler (*Cervus elaphus*) and Ua-25195 a wild pig Astragalus (*Sus scrofa*) were considered intrusive, having a very low agreement index of 1.9% and 1.4% respectively. When the problematic samples were removed, the total agreement index was 105.9%. When the final run was made, it was noted that the start boundary of this phase was contemporaneous to that of the 'transitional' Tågerup SU7 'Intermediate' phase (see below). This was not seen as intrinsically problematic, as the Ertebølle phase's layer 6 dates were used to ensure that the Ertebølle was fully accounted for, and because the Tågerup promontory is thought to be continuously occupied, despite complex sea level transgressions (Karsten and Knarrström 2001, 283). It is worth noting that there is no *a priori* reason to assume that one site has to be abandoned before a nearby site is established (see below).

4.17 Tågerup Intermediate radiometric data (SU7; see tab. 4.9)

This site, seen as transitional between Kongemosen and Ertebølle technological traditions, yielded eight initial radiocarbon results, from the culture bearing levels L20, L21, L22, Layer 103, and A1156 (Mårtensson 1999; Karsten & Knarrström 2001). When run as a group, the resultant agreement was high at 95%, and, consequently this was accepted for the final analysis without modification. The results indicated a wide duration of occupation, consistent with the range of archaeological material and the ^{14}C samples taken from different cultural deposits.

4.18 The final case-study chronological model.

A chronological model for the case study was then constructed in OxCal using the 'cleaned' radiocarbon data to determine the start, end, order and duration of each find-bearing phase. A series of OxCal commands were used to put the results into a logical order for presentation, and these are now explained. To be as inclusive as possible, the final model used all available ^{14}C results, and where the radiometric distributions were found problematic they were **Questioned** in OxCal, which left the probability distribution in the output plot, but excluded from the actual analysis. The final model was constructed by including each radiocarbon result in a bounded **Phase** for each site. This resembled a Harris Matrix linking all nine sites. After the model was initially run, the **X_Reference** function was then used to order each **Phase's** start/end **Boundary** to displayed the relative position of the boundaries on the same plot. An identical model with an **Order** command was then run to determine the probable order of the sites. Once the order was resolved as far as possible, a final model was run. Finally, the **Span** command was used to plot the most likely phase durations in terms of the actual carbon date distributions themselves.

4.19 The results

In the final run there are two sigma ranges below each distribution, 1-sigma at 68.2% with the short bar below the probability distribution, and 2-sigma at a 95.4% confidence level with the long bar below the distribution. As expected, the dates are tightly clustered; however, there are some clear trends emerging that are not obvious from Sørensen's (1996) box plot. The clarity of the different groups of start and finish dates provide a robust calibrated chronology which will be used in the subsequent projectile point and environmental analyses. The resultant distribution plots can be seen in **fig. 4.3-fig. 4.13.** All the data, result and models can be found in the attached **Appendix CD**, in the **OxCal file Ch_4_Phasemodel.** The final point-bearing phase 'total sites' model, has an overall agreement index of 105.5%. Each point bearing phase is plotted separately, so the agreement index of each sample, in terms of the overall final chronological model is absolutely clear. Please note that the agreement index levels of the samples in **fig. 4.3-fig. 4.13.** are now slightly different from when the data was initially analyzed above, as described in each phase's individual radiometric data. Now, instead of each phase being run individually to analyze its radiometric data in terms of an individual site-specific context, the final model, see **fig. 4.3-fig. 4.13**, was constructed and run in terms of all the previously vetted samples in all the phases. Where a sample is omitted from the final model, it was found to be incongruous in terms of *all* the radiometric data, in *all* the phases; not just its own phase's ^{14}C data. As before, it is left in the plot with a question mark against it e.g., Tag Ua-25191, where an agreement index with the model is calculated (i.e. 0%), but is not included in the final model's calculated start, end, or span results.

4.20 Start distributions

In the final nine step sequence (see **fig. 4.12**), Tågerup can be seen clearly as presenting the most distinct results, due to the high number of internally consistent radiometric determinations available. The Tågerup-Kongemose site start has very short boundary probability ranges at both 2-sigma 95.4% and 1-sigma 68.2% ranges at the start compared to the others, which means the start can be precisely dated to 6500 Cal BC. Villingebæk, Segebro, and Blak II seem tightly grouped whilst Kongemose seems likely to be early despite the long tailed distribution, Stationsvej and Månedale are loosely dates but they only have few radiometric dates compared to the other sites. SU7 is clearly the latest start horizon, which is just after Tågerup-Ertebølle.

The dates can be arranged by the highest peak of the probability distribution peak into an eight step time series, which serves as a working hypothesis, although the often long tailed distributions are problematic. Some of the phases clearly overlap temporally (see below). The sites with few ^{14}C results have boundary probabilities that have overlapping tails that would become shorter and clearer with more ^{14}C results. Therefore, a secure chronological time-step sequence would be a four-step time series such as;

1. Tågerup-Kongemose
2. Blak II/Kongemose/Månedale/Stationsvej
3. Segebro/Villingebæk
4. Tag Ert/SU7

The clearest three step series, in terms of all the sites in the analysis, in their start-order would be,

1. Tågerup-Kongemose
2. Segebro
3. SU7

4.21 End distributions

Again, the hypothetical order of the nine end boundary distributions are given in order of the highest and narrowest peaks (see **fig. 4.12**), although the long tails from the phases with few dates mean that this is not necessarily the best ordering. Nonetheless, it is clear that Blak II ends quickly, followed by Villingebæk and Segebro. Månedale, Kongemosen, and Stationsvej have long tailed distributions in the next group; whilst Tågerup is clearly defined as is SU7 at the end.

A three-step grouping of the phase-end boundary is,

1. Kongemose/Blak II/Villingebæk /Segebro
2. Villingebæk/Segebro/Månedale/Tågerup-Kongemose/Stationsvej
3. SU7/ Tågerup-Ertebølle

4.22 Site duration

The results of the **Span** command used in the model can be seen in **fig. 4.13**, and were as follows,

Villingebæk – very short duration, probability peaks at 0 years
Blak II – medium duration c. 500 years
Segebro – long duration, c. 900 years with a wide probability spread
Kongemosen – long duration c.600 years
Månedale – medium duration c. 400 years, with a long tail off from the probability peak.
Stationsvej – Medium duration c. 500 years
Tågerup-Kongemose – long duration and the shortest probability spread, c. 1200 years
SU7 – Long duration, c. 700 years
Tågerup-Ertebølle – Long duration, c. 1200 years

4.23 Discussion

In conclusion, the Bayesian method has produced a robust chronological model for the case study projectile point phases. Extant ^{14}C radiocarbon data was used to determine the start, end, order and duration of each find-bearing phase. The more radiocarbon and contextualizing stratigraphic data available the greater the accuracy of the time step hypothesis, as the start end borders probability distributions can be better differentiated, as demonstrated by the above Segebro data. In the case of the Swedish excavations, the results also present a clear diachronic framework to compare the morphology of points with the numbers and types of osteological evidence. The method used is highly flexible, allowing new ^{14}C results to be added as they are obtained in the future, and a new calibration curve to be used when they become available.

In terms of the projectile point data, the results indicate variable site durations for the case study phases. The Villingebæk phase is particularly important in terms of the validity of Vang-Petersen's typological method, as the results show the similar phase-duration criteria required for frequency seriation is not met here (Lipo et al. 1997).

It is also important to note that the results of this Bayesian model contradicts the traditionally held view that the Villingebæk phase comes before the Stationsvej phase. As this could prove a crucial point in terms of relatively dating the phases through seriation techniques (Vang Petersen 1979) this result warrants more radiometric AMS samples to be taken from Stationsvej osteological data, to establish a more accurate temporal sequence.

The OxCal Bayesian method demonstrates that the Villingebæk find-bearing layer is of short duration, whilst the other sites have medium to long duration phases. As the earliest phase of Vang Petersen's (1984) Kongemose/Ertebølle typological scheme is base on the seriated evidence from Villingebæk, the validity of this typology must now be questioned.

Chapter 5. Case study: lithic projectile point data

5.1 Introduction

There are three main objectives to this chapter. The first is to describe and explain the amount of morphological variation in, and between, the nine time-stepped assemblages in terms of the most useful continuous variables. Secondly, the aim is to present a simple graphical representation of the time-averaged technological characteristics of the different assemblages. Finally, the chapter concludes with a summary of results, and a series of hypotheses that the environmental analysis in chapter six can test.

The first part of the chapter introduces the methodological approach taken in terms of previous functional and quantitative approaches to south Scandinavian Mesolithic projectile technology. The lithic reduction sequence considerations are explained, prior to an outline of the problems associated with the potential misclassification of arrowheads. The next part of the chapter then describes the continuous variable recording strategy, explaining the approach taken concerning the arrowhead data sampling strategy in terms of the time-stepped phase-results obtained by the previous chapter. The overall lithic point analysis strategy is discussed, prior to a description of the case-study point data set itself on a phase by phase basis.

The main body of the chapter then presents the results of the quantitative analysis. A linked series of statistical techniques are applied to all the arrowhead samples in the nine case study phases. Only the relevant diagrams and tables will be presented and discussed here, as all data files, analyses and results, are stored in the accompanying CD. The analysis starts with a simple breakdown of single arrowhead variables using descriptive statistics, initially through examining mean and standard deviation of all arrow point single variables. The mean amount of variation for each point variable per site is calculated and displayed in a bivariate scatterplot. Secondly, the amount of variation in each single continuous variable is calculated using the coefficient of variation. Thirdly, a series of scatter plots are produced to examine every bivariate combination of the arrowhead variables. A discussion of the implications of the results is presented at the end of this section. Appropriate multivariate data-reduction techniques are then introduced and applied to the dataset. The classification technique of discriminant analysis is used to independently classify each arrowhead into its most probable archaeological phase of origin, in terms of the data from all the phases. This allows simple tabular representation of inter- and intra-site point relationships expressed in percentages, solely in terms of morphological similarities. Principal components analysis is then used to reduce inter- and intra-site morphological relationship-trends in all the continuous variables simultaneously into a less complex format, whilst retaining the maximum amount of original information (Shennan 1997). This allows the data to be presented in a simple bivariate scatterplot format. The two variables that contain the greatest amount of variation characterising the whole assemblage are determined. Finally, a consolidating bivariate plot is presented of these two variables, where the individual data points are then substituted by mean confidence ellipses. This time stepped diagram allows a simple presentation of the mean amount of variation for each arrowhead assemblage.

The final section explains the results in terms of known functional characteristics of the arrowheads, and the associated evolutionary issues and implications discussed in the initial section.

5.2 Methodological approach

There are specific methodological problems with existing classificatory schemes which have had to be circumvented by this study. The concept of a simplistic single developmental trajectory for south Scandinavian lithic projectile points has been reinforced by the simple evolutionary diagram presented by Fischer, who, following Vang Petersen's (1984) earlier frequency seriation work places 25 cultural phases, from c. 12,500 BC - 3,500 BC in a linear chronological sequence; each cultural phase represented by a single 'typical' point shape (Vang Petersen 1999, **fig. 3.2**; and Fischer's schematic diagram **fig. 3.4.** Although points of the particular shape can occur roughly around the chronological intervals Fischer provides, as the assemblages are often ^{14}C dated, his scheme is flawed for several methodological reasons. Firstly, the specific morphological types, which are often derived from type-sites, are not precisely time-stepped, as this was only recently possible with recent calibration program-modelling (see previous chapter). Secondly, as discussed in chapter one, there is no reason to assume a single inherent or inevitable mechanism of progress, or any single evolutionary trajectory, as is implied by the direction arrows of

Fischer's diagram. Thirdly, Fischer's evolutionary scheme fails to account for any variation in, or between, point-assemblages, as projectile point morphologies rarely fit the idealised categories that are presented. For instance, Swedish attempts to apply Vang Petersen's typological system have been repeatedly unsuccessful (Knarrström 2001). It is possible that in spite of a 100 km distance, Danish Blak phase points may belong to a separate interaction sphere, and a technological lineage unrelated to the early Tågerup points. It would seem likely that contemporary population levels are much higher and less mobile than currently thought (Karsten and Knarrström 2003). The typological anomalies could indicate a greater number of separate interaction zones, as the system apparently works well for Villingebæk phases on the Danish side of the sound. Either that, or the typological system is entirely wrong. Danish Blak and Kongemose typologies are disputed by Knarrström as a result of use-ware analysis. Knarrströme found that the early phase points in the Swedish Tågerup assemblage radiometrically determined as contemporaneous to Sørensen's Danish Blak II phase (1996) were not obliquely hafted, but transversely hafted and virtually identical to much later Ertebølle points (Knarrström 2003 *contra* Vang Petersen 1984, Sørensen 1996). Following Lipo's (et al. 1997) work on seriation method this disparity may be due to different populations producing different technological traditions with geographically separated interaction zones. Although a typological approach can be useful for broad heuristic purposes, Knarrström's evidence suggests this can lead to a circular dating argument. These problems will be addressed below.

Typological thinking has to be discarded in favour of more rigorous theoretical units of analysis. Designed for a frequency seriation, Peter Vang Petersen's exhaustive point variable recording strategy is detailed in **fig. 5.1** (Vang Petersen 1979; Vang Petersen 1984; Vang Petersen 1999). Vang Petersen did not use weight and thickness variables in his original seriation, and American studies have demonstrated these could potentially be important in terms of classifying different weapon systems (Thomas 1978, 461). In contrast, this study includes all weight and maximum blade thickness dimensions from all sites except in the case of the Blak II points, where only two dimensional scans were available (see **fig. 5.2**, and below, for the variables used in the current case-study).

Despite a near universal acceptance of excavators' interpretations of the function of the case study microliths as arrowheads on qualitative grounds, the assumption requires further quantitative qualification. Hafting orientation of projectile points is a key issue, and this requires further clarification here. Crucially, Vang Petersen's typological method cannot accommodate arrowheads that may have different hafting orientations than he presupposed. It can only tell them apart, classified by differences in the internal angle, dependent on knowing which dimension is the base. This proves to be a circular argument, as arrow head orientation on the arrow shaft was not independently tested by Vang Petersen. For instance, When Knarrström examined the Tågerup rhomboid points dated to the same period as the Blak II phase through use-ware analysis, they were actually found to have been transversely mounted, like the later extant Ertebølle arrows. An example of the evidence that Knarrström gathered is shown in the microscope photographs of **fig. 5.3**, and **fig. 5.4**, where the damage caused by high velocity impact is clearly seen on the base and tip of two early Kongemose/Blak phase points from Tågerup. This becomes clearer when the hafting orientation of south Scandinavian Mesolithic arrow heads proposed by Larsson is compared **(fig. 5.5, A, B, and C)**.

To clarify the hafting issue further, under Vang Petersen's scheme (see **fig. 5.1**) if the internal angle is less than or equal to 10°, it is then classified as an Ertebølle transverse arrow head type, as opposed to an Kongemosen oblique arrow head. This scheme can be a useful heuristic device. Most Late Mesolithic points are clearly derived from a rougher, less complex reduction strategy and look transverse by qualitative assessment, whilst all known surviving late Mesolithic hafted arrowheads are transversely mounted, as shown by the extant Ertebølle period examples (see **fig 5.5B**; Knarrström and Karsten 2003). However, Vang Petersen's scheme does not allow the *possibility* of points being hafted in a different manner that that originally assumed (Karsten & Knarrström 2003). This system assumes a unilinear direction of point evolution, which is not necessarily true (see chapter one). Without supporting evidence indicating the hafting direction provided by use-ware analysis, there is no way to distinguish which point-dimension is the base, and which is the opposite cutting edge. It follows that the internal angle cannot be consistently compared across assemblages, if it is taken from incompatible dimensions. Vang Petersen's choice of variable scheme may be appropriate if all arrowheads are hafted obliquely in the same way, which may be true of the Kongemose and Villingebæk assemblages; however, Vang Petersen's scheme does not allow for the possibility of any other method of hafting the arrowheads. The recording scheme adopted below makes no such *a priori* hafting assumptions, and in the final analysis uses the two least controversial dimensions determined to hold the most relevant information, for statistical reasons that will be demonstrated below.

It is worth reiterating that the default method of analysis used by the Danes - that of frequency seriation - is deemed inappropriate here. This technique used as a relative dating methodology, is best used heuristically for dating assemblages lacking radiometric data. Uncritical usage of frequency seriation can encourage a reorganisation of point variables until a convenient, rather than accurate, seriation is found. This seriation may or may not be representative of a time sensitive sequence of projectile point types, and can be circular if untested. If a relatively derived typological sequence is validated by radiometric data that coincides with a proposed typological sequence, as is the case with Vang Petersen's 1979 thesis, it gains widespread acceptance within the archaeological community. The necessary spatial 'interaction zones' described by Lipo (et al. 1997), are close together in this region which in principle should be an advantage, allowing a more meaningful and controlled comparison of assemblages. Several of the sites are in very close geographical proximity, for instance, Villingebæk and Månedale, which are less than a kilometre apart. However, the point data used here (see below) fails to meet the fundamental frequency seriation pre-requisite of similar phase durations (see previous chapter; O'Brien 2000; Lipo et al. 1997). An attempt to compare variation in a point assemblage that is probably a generation or two at most long with an assemblage deposited by over 40 generations duration is inherently flawed. If, for instance, a hasty typological comparison was made between the Blak II and early Tågerup phases, point data would not be compared on a temporal like for like basis, as Tågerup-Kongemose phase lasts for c. 1200 years, and Blak II for c. 500 years (see last chapter; **fig. 4.13**). In addition, it is suspected that the statistical signature emitted by the seven continuous variables traits used below do not exhibit enough independent variability to be theoretically valid, due to intrinsic material constraints of blade technology (Lipo 1997; O'Brien 2000). The addition of more variables to the analysis to force a seriation to work, e.g., colour/type of flint/raw material source, retouch shape etc., would be pointless.

The flint is predominantly from local primary Senonian and Danian and Kristianstad Moraine deposits, until the Ertebølle phase, when the secondary deposits from the immediate site areas are used (Knarrström 2001, 23); whilst basal retouch shape and internal angles are functionally limited by the rigid morphological constraints of the microblade or microburin technology used. The identification of a base dimension, identified as a key element for arrow hafting in chapter two, has been shown to be highly controversial, when the arrow head is not of a transverse type associated with Ertebølle culture. As previously mentioned, a unilateral hafting direction of all points from a given context is unsupportable on the grounds of evidence from Knarrströme's (Karsten and Knarrströme's 2003) functional analyses.

In summary, the resultant arbitrary nature of the established typologies (see **figs. 3.2; 3.3, and 3.4**) that clearly suggest a unilinear developmental trajectory are of little or no value for an evolutionary study.

5.3 Functional considerations

Use-wear analysis demonstrates that the lithic arrowhead technology is functionally variable and does not always improve through time (see above). Friss-Hansen's (1990) findings will now be analysed, as they demonstrate a fluctuation of arrowhead functional efficiency using a formal model of optimisation. Ethnographic evidence of hunting was analysed to calculate the most efficient arrowhead shape. Mesolithic arrows and modern hunting broad-headed arrows were compared. Friss-Hansen found the optimal use of hunting with bow-arrow for large game was using a close range shot with a broad-headed cutting arrow, in the same manner as practised by Ishi, last of the Yahi tribe (see chapter two). For a clean one-shot kill, an ideal range of 15-20m is desirable, 40m at maximum range. A shot through the thoracic cavity has the best chance of hitting the heart, lungs, and the largest arteries, but to an extent, the ideal shot depends on the prey species. Some hunters favour a diagonal shot through the rear of the body of the target-prey, as this is thought to induce the most blood loss in the shortest period (Friss Hansen 1990, 491). Arrows can quickly lose the necessary kinetic energy for a one-shot kill if a bone obstructs penetration, so different strategies are developed to maximise the chances of a quick kill. These are often prey specific; for instance, when hunting Great Plains' Bison, Native

American groups often favoured an aimed shot to the area behind the shoulder-blade, which presents the most exposed space between the ribs, specifically when the animal's front foreleg was fully extended. Friss-Hansen worked out the optimal sized wound for a one shot kill for various types of game, depending on surface area of wound in cm^2, compared to the weight of prey in kg, and thickness of hide for the prey type (Friss-Hansen 1990, fig.1). On engineering grounds it was found that when poisons were not applied, broad heads have the most optimal shape to enable a one shot kill, and width is the single most important dimension of the cutting arrowhead, as this directly affects the surface area of the wound (Friss-Hansen 1990, 495). Friss Hansen then developed a formal efficiency index for an arrow, derived by the formulae,

CI = HP:SC/HCSA:SCSA

Where CI is cutting index, HP is Head Perimeter, SC is Shaft Circumference, HCSA is head cross-sectional area, and SCSA is shaft cross-sectional area (Friss-Hansen 1990, 498, fig. 2). Assuming a consistent diameter of arrow shaft where the shaft does not survive but hafting orientation of the arrowhead is clear, the CI of Mesolithic and recent arrows were calculated and compared.

Friss-Hansen found the arrows from Stellmoor (c.8500 BC) had a high CI of 2.2-2.3, the Loshult Arrow from Scania (c.6500 BC) had a low CI of 1.5, the Vedbæk 4500 BC; Kongemosen (5500 BP) oblique points were at 2.0; and the 5000-4500 BC Bloksbjerg (near Copenhagen) arrow was high at 2.3. Modem metal broadheads were very high at 3.9, and Ishi's arrow CI was high at 2.2., although most Native American arrows (n.118 from twelve tribes) were found to have be low CI at 1.10. What emerges from an admittedly small Mesolithic sample, are general through-time fluctuations in arrow efficiency; e.g., the earlier Stellmoor arrows are more efficient than the later Kongemose arrows. This makes sense in terms of different populations having different social learning traditions, which can be lost as well as gained (see chapter one). Population level effects and the specific action of selection and drift will be modelled in the next chapter, after the morphological analysis of the case study arrowheads. Although the CI provides an excellent measure of optimal performance, the function and hafting orientation of some of the arrowheads here may be disputed, as no arrow shafts with arrowheads attached survive from the phases analysed below (see below). Use of Friss-Hansen's CI may also give an misleading indication of functional efficiency, when the arrowhead is devoid of selective context, e.g., the hunting strategy, as the use of baying or tracking dogs, and poisoned arrows are not taken into account (see chapter two). Instead, the data here is analysed initially only in terms of inter- and intra-site variation in point-continuous variables to identify aggregated phase level technological trends. After this analysis, the unprecedented amounts of extant environmental data will be used to identify the selective context at the aggregated phase level scale, in the next chapter.

5.4 Lithic reduction sequence considerations

The projectile points used in this study originate from two main types of blade technology. The first is that of indirect percussion using a punch blade tool (**see fig. 5.6, 5.7, and 5.8D**) often with an associated complex microburin technique to shape the individual projectiles, resulting in blades and subsequently microliths of a highly consistent maximum thickness. This technique is strongly associated with technology attributed to the Kongemose culture. The second blade technology is less complex, and is termed a hard hammer direct percussion technique, used to detach blades from a core, resulting in generally thicker blades, with characteristically less standardised microliths. This is a technology strongly associated with the Late Mesolithic Ertebølle cultures (see **fig. 5.8A, 5.8B**). It was anticipated that these differentiated reduction techniques should leave a clearly recognisable statistical signature.

Changes in faunal data representing prey alterations due to technological change (or vice versa) may coincide with these detectable changes in morphological variation (see next chapter). This may indicate whether certain points, or reduction strategies. were used for prey-specific hunting constrained by selection, or whether they changed due to stochastic processes driven by population level fluctuations. Initial qualitative assessment showed little available variation to be extrapolated from relatively similar rhombic, oblique, and transverse point shapes within the Middle to Late Mesolithic data presented here (**see figs. 5.5A, 5.5B and 5.5C**), compared to the variables potentially available with the bifacially reduced points more recently used in evolutionary studies by other analysts, such as O'Brien (et al. 2001; see chapter two). There is potentially much more morphological variation possible in arrowheads produced using a biface technology, than when they are produced using punched blade technology, due to inherently different manufacturing constraints; less morphological variation is possible when constructing a point from a blade, than from a bifacial blank. This inherent difference in potential point-complexity suggests that when an assemblage containing points from more than one lithic reduction tradition are analysed, the resultant assemblage variation may not be easily, or intuitively, recognizable. The statistical approach adopted below accounts for these possibilities.

5.5 Potential misclassification of microlithic arrowheads

The possibility of drill bits or other composite tools being misclassified as arrows by the excavators, or the recording of incomplete or resharpened arrowheads, was an initial concern. However, the combination of extant early and later Mesolithic hafted arrowhead examples, with diagnostic arrow knock-ends in the shafts (Karsten & Knarrström 2003), the experimental functional studies (Fischer 1988; Friss-Hansen 1990), and use wear analysis on samples of the different point data (**figs. 5.3, 5.4**; Grøn 1982; Knarrström 2001), suggests that the arrowhead samples used here are in fact finished projectiles, although many have been discarded before use, as they are often excavated in a pristine undamaged state. Fischer's studies (1984; 1988) demonstrate that lithic points often splinter or shatter on impact, leaving characteristic basal and point impact fractures, high velocity lithic striation fractures, and haft polishes seen in conjunction with impact point fractures (Karsten & Knarrström 2003). This allows a relatively secure method for arrow point diagnosis (see chapter two). Nonetheless, a healthy scepticism was maintained during the point data recording process, in case microliths were previously misclassified as arrowheads. Prior to statistical analysis, it was anticipated that misclassified points, perhaps those from a weapon system other than the bow-arrow, may manifest themselves as statistical outliers. This is why the multivariable classification technique of discriminant analysis was also used below. Thomas (1978) and Shott (1997) both demonstrated that this is a potentially powerful method for determining spear point from arrow points in North American contexts. Functional studies by Friss-Hansen (1990) suggest arrowheads can have optimal dimensions in terms of arrow shaft cross-sectional diameter to arrowhead cross-sectional diameter (see above). Given that prehistoric arrow shafts apparently varied little in cross sectional diameter, and this remains to be tested as the total extant arrow sample size is low; a given population of arrowhead cross-sectional diameters should cluster closely around a mean value. One cautious interpretation would be that those microliths with dimensions that drastically stray away from the mean may not be arrowheads. It is proposed that bimodal distributions may indicate different classes of arrow heads or weapon systems (see below).

5.6 The recording strategy

Metric data was recorded from over 3600 microliths classified by the excavators as arrowheads, from nine previously excavated southern Scandinavian sites, over five months during the summer of 2002. Each microlith was digitally weighed, then measured for maximum thickness, before being digitally scanned into a computer – this facilitated a three dimensional recording strategy. The two dimensional colour images were then measured using the measuring tool in Microsoft Photoshop, so a further series of five metric dimensions were recorded for each point.

The variables recorded are detailed in **fig. 5.2**, and for reference purposes that do not necessarily imply function, these are named edge, base, long diagonal, short diagonal and internal angle. With the previously obtained weight and thickness dimensions this gave a maximum total of seven continuous variables for each microlith. It is important to note that the edge and base dimensions are arbitrarily named here - unlike the long diagonal and short diagonal. Please note that these measurements are not necessarily those used by Vang Petersen for his original frequency seriation (Vang Petersen 1979; see **fig. 5.1**).

The internal edge angle is the angle that is made by measuring a straight line from the centre (*midtakse* - see **fig. 5.2**) of the shortest external dimension on the point (named the base) down through the centre of the point in a lateral line to the centre of the opposite edge (named the edge), and by then measuring the internal angle measured at the intersection of the line made by the edge with the lateral line – minus 90° (**fig. 5.2**). This differs from Vang Petersen, as his base dimension choice is not always the shortest external dimension, as is the case here.

All point variables were chosen to capture the maximum variation between comparable metric dimensions from point shapes taken from different assemblages and potentially different lithic reduction strategies. The variables were also chosen to avoid assuming different functions for different dimensions. For instance, the location and position of the hafting element/base and cutting edge could be counter intuitive, as functional analysis of the Early Tågerup arrow heads suggests that the contemporaneous Blak II points may also be transversely mounted rather than obliquely mounted (see Knarrström and Karsten 2003).

5.7 Analysis strategy

This section focuses upon discerning the units of analysis that complement the evolutionary perspective proposed in theory chapters one, two and three. Special importance is given to quantifying variation - or lack of variation - in overall point shapes and specific traits, for later comparison to changing diet breadth and environmental fluctuations.

It is proposed that the dispersal of certain traits through time and space, may reflect the scale, mode, and tempo of technological evolution (O'Brien and Lyman 2000). The initial aim of the point analysis is to identify the mean values of evolutionarily important traits, then to ascertain how they change through time. The objective is to graphically represent in the most parsimonious and elegant manner changes to a part of the bow-arrow weapon-system through time. This may or may not be the result of optimising technological strategies for specific prey-capture strategies by the past populations using and depositing the technology (see chapter six). However, as overall point size and wound infliction capability are considered functionally important and subject to selection (see chapter two), the following suite of techniques is designed to identify key attributes that capture the greatest amount of functionally relevant variation, so it can be simply displayed and compared between assemblages.

5.8 The data set

The chief problem prior to the analysis was how to meaningfully deal with such a large amount of potential data from 3600 points over nine sites, especially as the assemblage sizes ranged from 34 points in the case of Blak II, to over 1400 in the case of Tågerup. The solution was to take a random sample of 30 virtually complete points from each assemblage, giving a representative sample total of 270 points from the nine sites. Point tips from this random sample were often slightly chipped or broken, presumably due to taphonomic process as well as impact damage. However, when overall shape was largely intact, the perimeter dimensions were easily reconstructed from the scans using the measuring tool in Microsoft Photoshop. Rhombic, transverse and oblique points resultant from the blade technologies used present remarkably clear and uniform outlines when digitally scanned (following Vang Petersen's method, see the dotted lines in **fig. 5.1**). Where the points were clearly damaged beyond simple reconstruction, and these were surprisingly few in number across all assemblages, they were not used in the analysis sample. Where this slight reconstruction occurs, the metric weight dimension could be misleading – this has to be allowed for in the interpretation of results.

The resultant nine-site projectile point data set is statistically analysed below to determine inter- and intra-site variation and for complementary measures of relatedness, in their relative time stepped start-date order derived from the previous chapter. However, final interpretation must take into account site duration - also derived from the last chapter. The 30 points selected from each of the nine assemblages are presented for convenience in time-step start order, however the time-step end order may also be significant and this will be kept in mind (see below; **tables 5.1-5.9**). Each point has been given a reference number for the purposes of quick identification, next to the original excavator's find number. Digital callipers and digital scales were used for recording the continuous variable data, except with the Kongemosen dataset, which was already recorded, and kindly donated on a database by Peter Vang Petersen. This point data only required additional thickness and weight variables to be recorded. The Blak II data was measured from a scan of the points taken at the National Museum of Denmark, and has no weight and thickness variables currently available. With reference to **fig. 5.2** and **tabs. 5.1–5.9**, the seven metric units and abbreviations (where necessary) for each variable are recorded are as follows,

1. Edge – This is the side opposite the shortest dimension termed the base recorded in millimetres to one decimal place.

2. Base –The shortest perimeter dimension on the point, recorded in millimetres to one decimal place.

3. Longest diagonal (LD) – the longest diagonal distance across the point measured in millimetres to one decimal place.

4. Shortest diagonal (SD) – the shortest diagonal distance across the point measured in millimetres to one decimal place.

5. Thickness (THICK) – maximum thickness of the point recorded in millimetres to one decimal place.

6. Weight – recorded in grams to two decimal places. The same set of digital scales were used for all points in all assemblages for consistency.

7. Angle – This angle measures the deviation of the cutting edge angle from 90°. A lateral line is drawn along the major axis of the point, from the half way from the base edge to halfway down the cutting edge, and the resultant angle, where the cutting edge intersects this lateral line is subtracted from 90°, and is measured in degrees to one decimal place.

All the units of measurements are therefore ratio scale variables, known as *continuous numeric* scale variables or *real* values (continuous variables), which is important for choosing the most appropriate statistical techniques and for subsequent translation into the evolutionary terms, ideational traits and variables used below (O'Brien & Lyman 2000; Shennan 1997).

Where the site names are not used on diagrams i.e., in the output from the discriminant analysis and confidence ellipses, the site numbers below, or abbreviations, are used. These are time-stepped by start date (see above). Each site has some notes concerning certain specific details of the point-assemblage which are provided for clarity; however, see chapter three for more detailed site data, and chapter four for more detailed chronological data.

1. Tågerup Kongemose point data (**TÅG**). See **tab. 5.1**. Parts of this data-set predate and temporally overlap with what the excavators and Sorensen (1996) describe as the Blak phase (see below), and are known to continue on in an unbroken chronological sequence into the later Kongemose phase (Karsten and Knarrström 2001). This is important, as the earliest Tågerup points, those found closest to the earliest promontory shoreline, were analysed for traces of useware that could indicate the arrowhead hafting direction by Knarrström. They were found to be transversely hafted; whilst the Blak II points have not yet been analysed in this manner (see chapter three). According to the results of the previous chapter, this indicates that the earliest Kongemose points here, probably predate the Blak II assemblage points. Using Sørensen's (1996) classification terminology, this makes part of the Tågerup Kongemose assemblage currently the earliest known example of any of the known Kongemose phase points. As these are demonstrated by Knarrström to be hafted transversely, there is clearly no obvious straight line of evolutionary development from oblique to transverse arrowhead hafting method; Knarrström's use-ware sequence shows that the hafting of points changes again to a transverse hafting method, in the later Early Ertebølle period (Karsten and Knarrström 2003). The implications for the following point analysis is that the variable distributions that may represent the two different point traditions known to be present, may or may not separate neatly out into a bimodal distribution, due to the large number of available points available for the n. 30 sample size. However, the n. 30 random sample is still taken as a valid time-averaged representation for the entire n.1200, total for the specific purposes of this study. The total duration for the phase is c. 1200 years.

2. Blak II (**BLAK**) point data. See **tab. 5.2**. As discussed in chapter three, this point-data currently has no weight and thickness variables available, which may or may not make these points more difficult to classify, in terms of the other assemblages with all seven variables available for quantitative comparison. Due to a very similar blade technology, the point manufacturing tradition is assumed to derive from the earlier Maglemose culture (Sørensen 1996). On typological grounds, according to Sørensen and Vang Petersen, the Blak II phase is identified as a separate phase, being the earliest part of the Kongemose culture, just prior to Vang Petersen's (1984) Villingebæk phase. This is important in terms of the hafting traditions discussed previously, as these rhomboid points are assumed to be

obliquely hafted like the later Kongemose phases (Sørensen 1996). The following quantitative analysis helps to clarify the hafting issues (see below). The phase has a c. 500 years duration.

3. Kongemose (**KONG**) point data. See **tab. 5.3**. This is the type site, and the points upon qualitative examination generally demonstrate a very regular punched blade technology. A larger sample of points is available for this phase and has already been entered into a database at the National Museum of Denmark in Copenhagen; this data has also been analysed to compare the variable distributions from a much larger sample size (**n. 943**) than the sample size n.30 used here for all the point phases. It is important to note that the frequency distribution of the variables from the analysis of this larger sample size follows the same distribution trends of the smaller n.30 sample (see below). This phase is c.600 years long.

4. Månedal (**MÅNE**) point data. See **tab. 5.4**. These points, are unpublished data, but are considered as contemporaneous to the Villingebæk phase data by Vang Petersen (1979), on the basis of the seriation results and similar punched blade technology. The phase is c. 400 years in duration.

5. Stationsvej 19 (**STA**) point data.See **tab. 5.5**. This assemblage consisted mainly of punched blade technology, and was considered again contemporaneous to the Villingebæk phase of the Kongemose (**Brinch Petersen** 1975; Vang Petersen 1984). This phase is c. 500 years long.

6. Segebro (**SEG**) point data. See **tab. 5.6** This assemblage is characterised by punched blade technology attributed to the Kongemose period (Larsson 1982). This phase is c. 900 years long. Larsson's (1982) point analysis did not adopt the Danish typological method, and instead looked at ratios of point variables in terms of their distribution over the Segebro site-area.

7. Villingebæk (**VILL**) point data. See **tab. 5.7.** This assemblage's punched blade technology is the second earliest phase of the Kongemose in the Danish typological scheme (Brinch Petersen 1975; Vang Petersen 1984). The phase is very short lived, between 1-100 years, with the higher probability indicating a very short phase duration.

8. Tågerup Intermediate (SU7) point data. See **tab. 5.8.** The excavators are convinced that due to the combination of the different point reduction strategies present in the armatures, this assemblage represents a transitional period from Kongemosen to Early Ertebølle technologies (Karsten and Knarrström 2003). A quantitative point analysis goes a long way to clarify this issue (see below). This phase is c. 700 years long.

9. Tågerup Ertebølle (**TÅG ERT**) point data. See **tab. 5.9**. This assemblage is considered as representative of the early phase of later Mesolithic direct percussion blade and flake technologies, and consists of predominantly transversely hafted arrowheads (Karsten and Knarrström 2003). The phase is c.1200 years long.

The next section will explain the appropriateness of each statistical process before each set of results is analysed and summarised in terms of specific evolutionary processes.

5.9 Descriptive statistics

The first step taken was to run a series of descriptive statistical techniques used to identify obviously significant trends in the nine data assemblages, specifically to identify the mean values and associated measures of dispersion around the mean, using both pictorial and numerical summary methods (for frequency distribution summaries for each variable see **figs. 5.9-5.15**; for total results, see **Appendix CD file Ch_5_Frequencies.xls**). This is done to determine how much variation there is in the distribution of each single point variable for each of the nine assemblages, and how much each variable varies when the variables are combined between assemblages. Another aim is to determine whether or not the individual point variables are normally distributed, as this factor can be of essential importance when choosing the most appropriate multivariate procedure for the data (see below). Only when analysis of descriptive statistics are completed and certain data trends, for instance whether data are normally distributed, are recognised is it appropriate to apply specific multivariate statistical techniques (Shennan 1997).

Bivariate trait combinations will then be examined in this manner using a series of scattergrams, to note obvious relationships and possible statistical outliers - perhaps misclassified microliths, prior to more complex multivariate methods (Shennan 1997). It is anticipated that recognition of patterns in the data at the simplest level of analysis may present a fresh interpretative perspective on the arrowhead morphological development.

5.10 Descriptive statistical tables

A series of descriptive statistics **(Appendix CD file Ch_5_Frequencies.xls)**, were obtained for all the above point variables for samples from all nine sites. In isolation these results may mean little, however they can help describe assemblage variation, in conjunction with related frequency histograms for the variables.

Frequency distributions in the form of histograms of each trait combined for all the sites (n.270 points), were run on the data in SPSS, see **figs. 5.9-15**, to identify whether the data is peculiarly skewed, bimodal, or normally distributed, to establish how representative the measures of dispersion used, following Shennan (1997 ch.4). It was expected that if a trait clearly belongs to a different class of projectile, or a different lithic production tradition, the results may be skewed rather than normally distributed. Out of the seven variables from the combined nine site sample, the most peculiar distribution was that of the angle. The shape of the histogram, **fig. 5.15**, suggested that there may be two separate normal distributions for the angle variable. This did not fit initial expectations concerning the traditionally accepted lithic point shapes. The angle variable is particularly important, as the point types were determined by Vang Petersen (1984) largely by the obliqueness of the angle, which he subsequently classed as rhombic, oblique, and transverse arrowheads. One would therefore expect the angle distribution here to show three, instead of two peaks. Instead, this result is suggestive of two major point traditions; oblique and transverse arrowheads. As the total angle distribution was the most interesting, this was analysed further. Each site assemblage was deducted from the total in turn, and the distribution frequency was recalculated. The result was that only when Blak II, SU7, and Tågerup Ertebølle points were in total deducted from the total assemblage to be analysed, the result was a unimodal distribution. No other site, when deducted from the total assemblage, altered the total angle's bimodal distribution. It was found that each of the Blak II, SU7, and Tågerup Ertebølle sites exhibited a unimodal dispersal for the angle variable. It was concluded that as angle variable strongly indicates whether or not an arrow is transversely hafted, so these three phases may share a common technological tradition of transverse arrowhead hafting. The time difference suggests that this would be a case of technological convergence, rather than a single linear progression from Early Kongemose to Early Ertebølle phases. This data supports Knarrström's use-ware analysis ((Karsten and Knarrström 2003), that suggests the Blak phase points were transversely hafted.

The total assemblage weight variable frequency (**fig. 5.13**), and the short diagonal variable frequency (**fig. 5.12**), demonstrated a degree of skewness where the 'base' variable (**fig. 5.10**) did not. This may or may not be significant, as some scholars think there is an optimum weight for arrows, whilst basal hafting elements can be highly characteristic of a particular manufacturing tradition (see chapter two), so further analysis is required (see below).

5.11 Coefficient of variation.

The next phase of the analysis was to compare the amount of meaningful variation for each continuous variable in each assemblage. For each variable, standard deviation was divided by the mean and multiplied by 100, to establish the percentage of variation for each continuous variable (see **tab. 5.10**). This method is known as the coefficient of variation (CV), and is a useful standardised measure of dispersal that corrects for differences in the absolute size of the variables being measured (Shennan 1998, 44). The CV is calculated using the following formula,

$$CV = s/\tilde{Y} \times 100$$

Where s is standard deviation and $\tilde{Y}$ is the mean. In a study of variation in Acheulean handaxes, Vaughan (2001) employed a modification of this CV method on his continuous variables, which is termed the corrected coefficient of variation (CCV), to correct for his small sample sizes (n.251), spread over three groups, which came from the continents of Africa, Asia and Europe. The formula he used was,

$$CCV = (1+1/4n) \times (s/\tilde{Y} \times 100)$$

Where n is sample size, s is standard deviation and $\tilde{Y}$ is the mean. In evolutionary terms, following Dunnell (see chapter two), this may be very optimistically used to indicate possible functional and stylistic traits within classes of artefacts. Vaughn's model posits that, depending on the evolutionary mechanism operating on trait variables, selection and drift will produce different spatiotemporal patterning of the observed variation in these traits (Vaughan 2001, 145). Vaughan failed to mention how many samples were taken from each region; one suspects that his sample size was highly variable and he does not mention what the results of a simpler CV were on his data. He also failed to account for variation in selective environment, as his handaxes, unlike the data presented here, were devoid of archaeological context. Due to the consistent sample level in the current case study data, when the CCV formula was applied to the case study data, this made less than 1% difference to the resultant percentage of variation for each variable. This was as expected, so the CV was used here as the clearest method of describing the trait-variation in percentages.

The CV totals were quantified (see **tab. 5.10**), and bar charts for easy time stepped comparison of changes to the variables are shown in **figs. 5.17- 5.22**. The most significant results demonstrated relatively large amounts of variation in the angle variable (**fig. 5.22**), with Blak II at 52%, SU7 at 90.2% and Tågerup-Ertebølle at 75.88%, whilst the remaining sites were all below 30% with the highest being Tågerup at 28%. This could indicate different degrees of certain evolutionary forces, and different technological traditions, as this dimension demonstrates the most radical changes from site to site. It would appear that a consistent angle was not so functionally important at Blak, SU7 and Tågerup Ertebølle, i.e., for the transverse arrowheads, and this may be due to a different prey-specific capture strategy. This hypothesis will be tested in the next chapter. The relationship between time averaged variables will be returned to in the next section.

5.12 Bivariate scatter-plots

The second stage of analysis uses a series of scattergrams, where one variable is plotted against another (Shennan 1988, 127), to depict the relationship between all the different variables in each point assemblage that may be of time averaged evolutionary significance (for all scatterplots for all sites and variables, see **Appendix CD file Ch_5_Scatter_A.xls; Ch_5_Scatter_B.xls)**. However, a significant correlation between traits may be identified and explained here on the grounds of inherent mechanical constraints in the lithic blade technologies, rather than any evolutionary process, prior to more complex multivariate analysis. It was anticipated that this stage should at least identify statistical outliers that may not be arrow points.

179 scattergrams were generated for the entire data assemblage in terms of the variables within the individual sites. Interestingly, the results failed to depict any consistent bivariate relationships across the phases, although certain relationships with size and shape were clearly more characteristic of some assemblages than others. All outliers were noted, although when checked against the original data **tabs. 5.1-5.9**, there were no samples that posed enough of a threat to justify removal from the overall sample, as several outliers should be expected in an assemblage this size. This suggests that the projectile points used in this analysis do comprise a homogeneous group, and are therefore probably resultant from the same weapon class, namely the bow-arrow system. The scattergram results for the individual sites are presented with linear trend lines with r^2 scores (coefficient of determination) where they are significant (Shennan 1997, 142), although they are on the whole remarkably low. Surprisingly, it was difficult to find a consistently strong bivariate relationship between even long diagonal and weight across the assemblages in most cases, as a size correlation might warrant, as the shapes qualitatively appear very regular.

It appears that despite their homogenous appearance, the points can be highly variable in their morphology.

The highest r^2 scores were yielded by Tågerup (**fig. 5.23**) for edge vs. long diagonal at 0.56; Kongemose (**fig. 5.24**) at 0.64; Månedale (**fig. 5.25**) thickness vs. weight 0.61; SU7 (**fig. 5.26**) at 0.4; and Tågerup Ertebølle yielding the highest values, (**fig. 5.27**) long diagonal vs. short diagonal at 0.60, (**fig. 5.28**) short diagonal vs. weight at 0.65, and long diagonal vs. weight (**fig. 5.29**) at 0.68. Unfortunately the weight variable was not available for the Blak II points, although edge vs. base r^2 value was relatively high at 0.45 (**fig. 5.30**), and long vs. short diagonal was at 0.38 (**fig. 5.31**).

The most significant results could be seen in the chronologically later assemblages, where as above, the angle variable separated the points out into two groups in SU7, best shown in **fig. 5.32**, edge vs. angle. This would appear indicative of two differently grouped point shape traditions, perhaps with oblique and transverse haft orientation, supporting the excavators' transitional site hypothesis.

The Tågerup Ertebølle group demonstrated the most number and highest values of significance. It seems safe to say that as the use-ware analysis determines these points to be transversely hafted, the characteristic variable dimensions associated with this simpler lithic technology are highly distinctive. This is a counterintuitive result as the more elegant blade technology of the Kongemose phases *looks* more regular, in purely qualitative terms. Whether or not this difference in variability between points from two reduction strategies is related to a difference in adaptative function, is a moot point. Both strategies may or may not reflect an optimal solution in two different selective contexts, so this problem will be returned to in the next chapter.

5.13 Mean total scatter grams

Bivariate scatter plots were then constructed (see **table 5.11**) to establish the mean values of the variables against each other, in other words, to describe the mean amount of interassemblage trait-variation **(for all mean total variable-scatterplots see Appendix CD file Ch_5_Scatter_C.xls;** for those mentioned in the text, see **fig. 5.33-36**). This was to see how the assemblages grouped over time, and how they matched up to the archaeological prior information concerning different lithic traditions. It was anticipated here that time averaged traits may produce clear patterns of relationships between the assemblages.

The results were very distinct, as the mean values separated and grouped clearly. By way of summary, Tågerup Ertebølle was in every case separated out from a main cluster, and often joined by SU7 and Blak II, away from the central group of the remaining six sites, in all the scatterplots. The lack of Blak II scores in some results (e.g. **fig. 5.33**) is due to the lack of a thickness and weight variables available. Nonetheless, Blak II seems to be separate from the SU7 and Tågerup Ertebølle values, apparently due to the different lithic blade technology according to Sørensen (Sørensen 1996). If Blak II arrowheads are from a different transverse point tradition, this may also explain the same gradient of slope shared by the mean long and short diagonal between Blak II, SU7 and Tågerup-Ertebølle (**fig. 5. 34**), as this value is highly indicative of the degree of 'transverse-ness' of an arrowhead, gauging from the previous results.

The remaining mean total values, from phases that are tightly grouped chronologically, comprising Tågerup-Kongemosen, Kongemosen, Månedale, ST19, Segebro, and Villingebæk remained on the whole tightly clustered. This supports a view of very similar technological traditions 'locked in' over a remarkable period of time. This could be explainable in terms of stabilising selection, perhaps representing an optimum shape for a given selective environment. This result has great significance for the establishment of different optimum shaped points used at sites that may correlate with corresponding time-averaged faunal assemblages. One would hypothesise similarly constant faunal count data to verify this hypothesis (see next chapter).

Another interesting trend concerns the thickness vs. weight variables, as despite the Blak II data absence, the blade technology appears consistent concerning point thickness across groups (e.g., **fig. 5.35**), whilst the weight variable separates out the groups neatly (**fig.**

5.36). As the weight only varies by c. 1 gram, this may not have a significant affect on the arrowhead. However, assuming a similar shaft weight (and this is a big assumption made by Friss Hansen 1990), the Tågerup-Ertebølle arrow points are heavier than the others. With the greater number of variable correlations from the previous section, it seems possible that the Early Ertebølle points may be closer to an optimum in terms of weapon system performance characteristics, than the other assemblages.

To explore ideas concerning distinctive transverse Blak II, SU7 and Tågerup Ertebølle traditions, and to analyse the apparent lack of variation in the Kongemose phases, it is time to turn to multivariate statistics.

5.14 Discriminant analysis

Discriminant analysis (DA) is a powerful classificatory technique that utilises prior archaeological information - the fact that each point assemblage was found in a separate archaeological context (Shennan 1997, 351; Shott 1997; Baxter 2003). DA is particularly useful here as it independently classifies the data into the most probable assemblage of origin - using just the known relationships between each site's trait variables in the analysis. DA is used here to explicitly account for and visualise the amount of intra- and inter-site trait variation. To enable the DA to work, each assemblage had to have the same number of variables, so in the initial runs, the weight and thickness variables were removed because the Blak II phase did not have them. Subsequent runs of the DA removed the Blak II points so the other sites could be analysed in terms of all seven point variables. Due to the limited output display of SPSS 11.0, the site numbers (1-9) had to be used as labels in scatterplots. By using scatter plots of individual cases in terms of resultant discriminant function's eigenvalues (the latent root of the resultant correlation matrix, Shennan 1997, 279), the trends between different traditions of point manufacture, within and between projectile point assemblages of calendar dated duration can be more easily visualised (e.g., **fig. 5.37**). The previous useware and quantitative analyses have shown a key relationship between Blak II, Tågerup Ertebølle, and SU7.

The results were very positive. The complete set of results can be found in the **Appendix CD**, under file **Ch_5_DA.xls**. The first run included all sites 1-9, and the resultant scattergram of DA function 1 and 2 by case, visually separated out by site (see scatterplot **fig. 5.37**). The group centroids clearly reflected the same trend – Blak II (site 2) was away from the main cluster, whilst SU7 (site 8) and Tågerup (site 9) overlapped to a degree - but were still in separate clusters.

More formally, the success of the classification is assessed in the classification results table, (see **tab. 5.12**). The overall results are that 51.5% of the total cases were correctly classified by the DA into the respective site phases.

Blak II (site 2) had 90% of the cases correctly assigned which is the most of any site; this indicates a very distinctive technological tradition. Interestingly, Stationsvej 19 (site 5) is closest to the Blak II in terms of the resultant classification in terms of the morphology as two Blak points were classified as Stationsvej 19, whilst one was classified as an SU7 point.

SU7 (site 8) had 63.3% of the cases correctly assigned, and Tågerup-Ertebølle (site 9) had 70% of the cases correctly assigned. 23.3% of the SU7 sample was assigned to Tågerup Ertebølle, indicating a closer technological relationship with this later group than with any earlier one, including Blak II. The temporal ordering of the phases shows that there is a chronological overlap between SU7 and Tågerup-Ertebølle.

Tågerup-Ertebølle scored highly as it had achieved 70% success in correctly identifying its own points, with 30% attributed to SU7. This indicated a radical break from the bulk of the other sites, although the DA classified two points to site 1 (Tågerup) and to site 3 (Kongemosen) respectively. The bulk of the classification was confirmation of differential hafting strategies (i.e., transverse) at Tågerup-Ertebølle. These results suggests that distinct technological traditions are recoverable by this method.

The remain cluster of point phases (sites 3-7) varied in classification success with a low level of successful classification, as would be expected for a homogenous technological tradition, although the highest percentage classification was accurate in each of these six sites. The long duration of these homogenous traditions, c. 1200 years, is remarkable.

Importantly site 1, Tågerup, had the next highest success at classification, with 33.3% of cases correctly assigned. This was not surprising as it spanned the earliest phases which might be more distinctive, but nonetheless no points there were classified as Blak II points. The bulk were instead assigned to sites 3-7, with two points assigned to Tågerup Ertebølle. It is clear that there is no evidence of 'mixing' in this assemblage, as the results are remarkably consistent. The long duration of the site and the large sample size to draw on can explain the bulk of classification assigned to the central group of phases, rather than to the early Blak II assemblage.

The DA was repeated, and sites were subtracted one after the other in the analysis as this is thought to give the clearest indication of any relationships (Clive Orton Pers. Com.). In each case the resultant two function scatterplot placed the Blak II cases distinctively away from the main cluster. The final analysis was run including just the main body of sites (1, 3, 4, 5, 6, and 7) as indicated by the scattergram (see **fig. 5.38**), with the extra two weight and thickness variables included (as the Blak II data was excluded). It was thought this may show clear differential clustering of sites. However, there was little discernable group separation. All group centroids were tightly bunched, with the lowest result from any of the analyses of only 42.8% correctly identified cases in total (see **tab. 5.13**).

5.15 Principal components analysis

As this analysis uses solely continuous variables, and the variables are in the main normally distributed, principal components analysis (PCA) is used as an un-weighted data reduction technique (Shennan 1998, 269). This is used as a multivariate compliment to the DA. SPSS 11 was used to carry out the PCA. Normality has to be assumed for the entire assemblage prior to the analysis (Hair et al. 1998), although the skewness of certain variables for the total, i.e., for short diagonal and weight variables has been noted (see above).

In qualitative terms PCA is scale dependent, so in this instance the variables have to be compared on a like for like basis. Again, all the thickness and weight data has to removed if Blak II points are to be included in the final analysis. The process then reduces a large amount of data to a smaller amount of data, whilst retaining most information contained in the original variables. This method is usually considered a logical 'multivariate first step' for analysing relationships between variables and cases, in this case it is used to complement the DA, and to identify the two variables that hold the most characteristic data for all the assemblages, to enable the clearest time- stepped diagram possible to show the technological relationships between the phases (see below). This technique creates a reduced number of new variables from the original set, in this case expressed in terms of a function. When related back to the original variables and cases (see **tab. 5.1-9**), this function enables a simple visualisation of relationships between variables and groups of variables; high figures are positively correlated variables, whilst negative component scores indicate negatively correlated variables. Again, the full set of results and tables can be seen in the **Appendix CD**, under the file name **Ch_5_PCA.xls**. By using bivariate scatter plots of the individual cases in relation to their principal components (Shennan 1997, 279) the cases can be colour coded according to which site they belong to, so the results can be clearly displayed (e.g. **fig. 5.39**).

The first component is usually size related (Blackith & Reyment 1971), and when compared to second or third components (or more if they are significant i.e., possessing an eigenvalue of over 1, ibid.), more interesting patterns or shapes of morphological peculiarity can be extrapolated from the data, despite the variables lacking the thickness and weight data in this case. The component scores were then saved as variables and placed next to the original cases (see **tables 5.1-9**) for easy reference.

The PCA was intended to be used to enable analysis of variables, cases and groups of cases that may help identify key point variables that contain the most information concerning functional size and shape attributes, and to aid comparison of variable-case relationship with the previous descriptive stats and the DA. To this end two PCA analyses were run on the data. The first was to include all the sample point data from the nine sites, the second was to exclude Blak II, SU7 and Tågerup Ertebølle data.

The results from the first PCA that includes all sites are shown in **tab. 5.14**. The component scores for the first two principal components were recorded as variables and are included in **tabs. 5.1-5.9 under 'PCA Comp. 1 and 2'**. These scores were then plotted as variables in a scatter-plot, see **fig. 5.39**. The output demonstrated some interesting trends. The plotted variable scores patterned out into four distinct groups, following the same pattern as the total mean scores for the variables in the previous section. The bulk of Blak II cases are clearly separated, and to the right of the mass of six sites, which formed another distinct cluster. SU7 and Tågerup Ertebølle overlap as separate groups at the bottom of the plot, SU7 spreading from the mass of the remaining six sites into the Tågerup Ertebølle cluster. This would support the view that SU7 is a transitional site, on technological grounds as proposed above, due to the apparently time-stepped and graduated relationship between the variables in the SU7 and Tag Ert assemblages. The Blak II phase appears as a separate distribution, even from Tågerup projectiles - where certain points are deemed earlier in absolute chronological terms (see last chapter). This may be direct evidence of non-linear evolution, and will be investigated further below.

The analysis was repeated, this time by omitting the Tågerup Ertebølle, SU7, and Blak II phases. This run used all available variables including weight and thickness - as Blak II data was not included. The resultant scatterplot of the cases (**fig. 5.40**) against the two principal components showed no structure. This scatterplot is thought to represent a case of long-term morphometric stasis, due to the long duration of most of the sites. This time the component plot showed much more separation of variables than previously. The component loadings showing the relationship between variables (**tab. 5.1-9**) shows that from the first PCA analysis, size was positively correlated to both components one and two, which between them explained 81% of the variance (see also **tab. 5.16**). When the individual case scores were compared it was clear that the long diameter and short diameter presented the most significant indicator of this size related variation. As the dimensions containing the most information about point size variation, these variables can be displayed using ellipsoids of the mean values of short and long diagonals for all cases, to give the clearest indication of through time changes to size relationship of the point traits that best discriminate between the groups (see below). The results supported the hypothesis of a homogeneous projectile technological tradition within this group, separate from the three sites excluded. As the PCA results do not display a time sensitive horse-shoe shaped curve indicating a seriation for the arrowheads, this is taken as further evidence that they do not meet the requirements of phyletic seriation following Lipo (et al.1997). This evidence invalidates Vang Petersen's typological method.

5.16 Confidence ellipsoids

A final quantitative method is used to generate confidence ellipses around mean values characteristic of the most significant trait variables in a simple scattergram format. This technique is used to visualise relationships identified as important by the previous statistical techniques (**fig. 5.41, 5.42**).

As long diagonal and short diagonal are two variables that represent a great deal of characteristic morphology of the different assemblages, when the PCA and DA loadings on the cases and variables were compared (see above), these variables were used in the final scatter-plots to characterise each assemblage. The full results of the analysis can be seen in the **Appendix CD**, in the file **Ch_5_Ellipse.xls**. The confidence ellipse program used here was created in Microsoft Excel, by Bill Grimm of the University of Columbia Missouri. The ellipsoids that bound each assemblage are initially calculated to constrain the ellipse at a 90% confidence level in relation to the population. Bearing in mind the above results, it is proposed that the size and orientation of the resultant elliptoids represent the most significant technological characteristics of each assemblage, in the most parsimonious and graphically clear manner available. Furthermore it is hypothesised that the mean ellipsoid orientation and spatial positioning used here, may be functionally related to bow-arrow technology between projectile point assemblages. This data may be highly useful for the interpretation of the proposed relationship with contemporaneous faunal assemblages. A series of related functional-adaptative hypotheses will be tested in the next chapter.

Fig. 5.41 displays a scattergram that represents the characteristic variation of the nine arrowhead assemblages, but the relationships are obscured by the many data points. The mean confidence ellipse program initially calculated the ellipse for the population mean based on a sample with a sample size adjustment (Baxter ibid.). The final diagram without the data-points, **fig. 5.42**, shows the mean confidence elliptoids at a 90% confidence level, leaving just the orientation and relative size of the ellipses. It is proposed that this is an excellent way of potentially indicating variation in the lithic technology, especially if there is clear stability over time in the lithic projectile morphology. When the resultant mean is used for the ellipses (**fig. 5.59 and fig. 5.60**); still constrained at the 90% confidence level), there are distinctive differences between Blak (2), SU7 (8), and Tag Ertebølle (9), which are clearly separated out from the main cluster. In further contrast to the main cluster, they are orientated in the same direction compared to assemblages (phases 1, 3, 4, 5, 6, 7) which form a very tight cluster. This close relationship indicates at least two distinct lineages of technological traditions.

A time averaged representation of each arrowhead assemblage's morphological variation is very useful. In terms of selection, it is hypothesised that the Tågerup Ertebølle (9) group is at a functional optimum, SU7 (8) and BLAK (2) is possibly moving towards the same transverse optimum and may be 'transitional' or unstable, whilst stasis in the Tågerup (1) and Kongemose (phase 1, 3, 4, 5, 6, 7, 8) groups are the result of stabilising selection at another optimum. This is interesting, as different mean distributions may be seen at different times and places – this may indicate different traditions moving towards, or away from, an optimum, given a constant selective environment. It is reasonable to suggest that following Friss Hansen's (1990) arguments that there is only one optimum for each arrowhead shape, and that the Kongemose 'slashing' shape is more functionally efficient for large ungulates, than the simpler, narrower, transverse arrowhead. On the other hand, the transverse arrowhead may be a more optimal solution when hunting a wider range of prey types, as it costs less in terms of manufacturing and teaching time (see chapter three). The different hunting strategies that may or may not be employed with the different arrowheads are clearly important. The only way to explore this relationship further is to study time-averaged environmental changes, especially faunal variation (see next chapter), on the same scale as the point analysis. In conclusion, the time stepped ellipse orientation (see **fig. 5.42**) represents the clearest available method available for representing mean lithic point morphology of each assemblage.

5.17 Summary

- This chapter has quantified variation in and between the time-stepped lithic assemblages. Previous approaches to Scandinavian arrowheads have been discussed with special reference to techniques of seriation and functional analysis.
- Use-wear analysis of the earliest Tågerup points that may chronologically correspond to the Blak II phase points indicated that both groups may have been transversely hafted. This has been explored using statistical techniques. Although Tågerup (phase 1) has the earliest start boundary date, the large sample size from a long duration site explains why these did not correspond morphologically to the Blak phase points. Unfortunately, the currently available point data does not allow the sub-division of the Tågerup phase into an early (Blak) phase and a later Kongemose phase, as the spatial location of the earlier points are not divisible in terms of the ^{14}C. The Tågerup phase is currently only divisible in terms of an arbitrary spatial split, which is deemed here as a potentially circular argument, i.e., the shapes look oblique, so they must be early Blak phase points. It is hoped that future research will resolve this problem.
- Despite a large randomised sample of points from all assemblages, the lack of outliers from the variables analysed by the descriptive statistics suggests that the uniform nature of projectile points used in this analysis were correctly classified as arrowheads, and unlikely to come from other artefact classes.
- The chronologically central group of Kongemose phase sites was remarkably uniform, indicating a common technological and social interaction sphere.
- The bimodal frequency distribution of the angle variable indicated that Blak II, SU7, and Tågerup Ertebølle had different technological tradition than the Kongemose group (phases 1, 3, 4, 5, 6, 7).
- The coefficient of variation demonstrated a consistent angle variable was not in evidence at Blak, SU7 and Tågerup Ertebølle which indicates a common transverse hafting tradition, and may or may not be due to a prey-specific capture strategy in the main Kongemose group (phases 1, 3, 4, 5, 6, 7). Vaughn's method of attributing drift and functional characteristics to points solely on inter-assemblage

morphological variation requires qualification in terms of selective environment. This will be tested in the next chapter.

- Multivariate analysis supports the hypothesis that the Blak II phase appears to have morphological characteristics closer to the SU7 and Tågerup Ertebølle assemblages. As Blak II point technology was similar to the main Kongemose group of sites, it seems this is likely to be a technological precursor as suggested by Sørensen (1996). However, without assuming hafting orientation, the morphological characteristics of this assemblage are clearly much closer to SU7 and Tågerup Ertebølle, suggesting an independent transverse innovation horizon for early Blak II phase points in support of Knarrström's conclusions (2003).
- In terms of selection, it is hypothesised that on engineering and experimental grounds (see Friss-Hansen 1990) the Tågerup Ertebølle (9) group is approaching an optimum shape for the transverse arrow shape. SU7 (8) and BLAK (2) are possibly moving towards the same optimum due to directional selection (see **fig. 5.42**). Morphological stasis around a mean point in the tightly clustered Kongemose phase group (1,3,4,5,6,7,8; see **fig. 5.42**) may be the result of stabilising selection at another optimum, with a different shape of obliquely hafted point. It is worth noting that given a constant selective environment, using Friss-Hansen's Cutting Index as a guide, the slashing points found in the main Kongemose group of points are inherently more effective at hunting large ungulates than the transverse shapes. In addition, the different traditions may or may not correspond to different prey capture strategies, for instance individual stalking and tracking, as opposed to mass kills. These hypotheses require testing using the selective environment at an appropriate scale.
- The mean confidence ellipse diagram (**fig. 5.42**) represents the mean variation for the different time stepped technological traditions, in and between assemblages. This diagram will be compared to mean changes in osteological evidence at the phase level where available, to determine whether or not there is a functional relationship between prey-type and point shape. If there is not, a drift mechanism may be tested as an explanatory mechanism for technological change.

Chapter 6. Demographics, ecological change, and arrowhead technology

"The number of wild animals within his reach, combined with the facility, with which they may be either killed or insnared, (sic.) must necessarily limit the number of his society."

(Thomas Malthus on North American hunter gatherers, 1798/1826, Book I, ch. IV)

6.1 Introduction

This chapter attempts to isolate the evolutionary processes that cause the changes in arrowhead morphology identified in the previous chapter. A population level model is an ideal scale to judge the success of a technological innovation. Consequently, demographic reconstruction is a central objective here. Successful technological traits should be strongly selected for, as they can directly affect the inclusive fitness of an individual. Population levels can be a barometer for the action of directional selection on a particular technological trait. Assuming all other cultural adaptations remain constant, and no other environmental fluctuations affect available prey-capture rates, population levels will go up, if environmental carrying capacity can be increased by a functional technological trait. Fertility rates could increase away from low levels probable in a marginal environment. The converse is true; in general terms a population will drop if it exceeds the carrying capacity of the environment, through increased mortality rates through malnutrition, increased levels of violent conflict and perhaps more importantly, through decreased fertility rates in times of stress (Hill and Hurtado 1996).

The role of inter- and intra-group violence was previously thought to be a key part of a demographic mechanism where environmental circumscription regulated population in a simplistic manner (Carneiro 1970). It now seems that the role of conflict is far more complex than this. For instance, Chagnon notes that most instances of inter-group violence amongst Yanomamö, occur due to the abduction of women, revenge, and prestige, rather than resource stress, and presumably these factors together can provide a powerful positive feedback mechanism causally related to an individuals inclusive fitness. However, it follows that the tempo of processes can be accelerated by an unpredictable, and often marginal environment. Cross-cultural ethnographic and anthropological studies indicate that when there is less to loose, in a dangerous environment where life expectancy is obviously short, people tend to be more prone to lethal violence, and also more prone to reproduce at a younger age (Wrangham and Petersen 1996; Chagnon 1997/1968). In terms of prehistory, if this theory holds, then in times of environmental uncertainty, populations may in general terms tend to quickly increase when they can least afford to; a situation which could lead a massive, demographic crash that may be archaeologically recoverable.

It has been previously argued here that the role of directional selection and adaptation, is often overplayed by behavioural ecologists and processual archaeologists (see chapter one). However, this does not mean that these approaches are incompatible with a cultural transmission framework. Interestingly, Fitzhugh (2001) develops a behavioural ecology framework for the role of risk, arguing technological innovation is risk sensitive; when return rates drop below a certain threshold, individuals are more likely to innovate, as they have less to lose. It follows that environmental change could be a causal mechanism both for new innovations, and the loss of complex technologies; bearing in mind the resultant adaptations are not necessarily going to work, and could have disastrous demographic consequences in a marginal environment. The role of random forces are equally crucial as directional selection, at the population level (Shennan 2002; Henrich 2004). Neutral theory states stochastic drift occurs if traits are not subject to selection, whilst randomly generated traits (mutations) reach fixation quickly in smaller populations than in larger ones (Neiman 1995). There is no *a priori* reason why these traits should have a positive effect on a population. Crucial fitness-enhancing innovations can easily disappear due to drift, as specific traits, or entire techno-complexes (such as weapon systems) will be removed from a population if the population drops to the level where those with the specialist production knowledge are randomly lost (Shennan 2002). It is quite possible that a given technology can sit asymmetrically to an individual's or group's inclusive fitness, whilst cultural innovation and transmission rates can be quasi-independent of genetic transmission, in terms of drift as well as selection processes (Boyd and Richerson 1985; Neiman 1995; Shennan 2002; see chapter 2). These different factors and processes are accounted for below.

The controlled chronology of this case study enables these theories to be tested at the population scale. Human population fluctuations may or may not correlate with technological time-averaged changes in the case-study arrowheads. As archaeological evidence suggests that there is a continuation of population in the region after c.10,000 BP (Brinch Petersen 1973; Vang Petersen 1984; Larsson 1979; Karsten and Knarrström 2003), it is hypothesised that changes in complexity of arrowhead technology in the case study data, i.e., crudely put, a shift from complex blade technology in the early phases, to a less complex technology in the later phases, are due to a loss of associated technological knowledge, which is directly related to population fluctuations.

The remainder of this chapter is divided into four sections. Firstly, published osteological data from four Swedish phases is statistically analysed to identify potentially functional relationships between different arrowhead shapes, and probable prey-types. This is accomplished by using NISP and NTAXA data to infer specific prey-types, following a recent method developed by Grayson and Delpech (1998, see below).

Secondly, fluctuating regional human population levels are modelled as securely as possible. The method developed here uses calibrated ^{14}C data to combine mean time of settlement phase occupation, which is used on a regional scale as a population proxy. This is a refined version of the method recently used by Gkiasta (et al. 2003), that uses a Bayesian OxCal model (see below).

Thirdly, faunal and human populations are shown to be independent of any environmentally induced geographic circumscription caused by overall reduction in land mass relative to rising sea levels, in the case study region. This is done by taking a simple ecological model developed for Mesolithic Britain c.7000 BP by Maroo and Yalden (2000), and using it as a proxy for the changing landmass of Mesolithic South Scandinavia. Current estimates of possible human population densities for the period are compared to the population densities of contemporaneous faunal species, as hypothesised by Maroo and Yalden (see below). It is proposed that changing densities of the faunal species are not likely to negatively affect the absolute numbers of human population. The model demonstrates that the human population is unlikely to be at the environmental carrying capacity, as even in the worst-case scenario, there were not enough people in the landscape to be affected by a reduction in the number of animals. It is proposed that any short-term problems of population-patch circumscription, are further offset by the increased number of highly productive marsh and estuarine environments that are likely to be created as the sea level rises, and by the simultaneous increase in the number of complex resource exploitation adaptations, that clearly support large local populations in the Ertebølle phases.

Fourthly, published pollen analysis of the case study region are reviewed, and found to indicate a continuous spread of deciduous species across the region through time. As such, there are no patterns of changing habitation in terms of reduced amounts of forest that occur in the region. It is proposed that any loss of forest in the period of the case study that may effect the faunal and human populations is likely to be offset by the creation of new, and more productive, estuarine and marsh environments.

Finally, climatic causes for fluctuating population are tentatively modelled. Isotope evidence is used as a proxy for regional temperature and precipitation rates. The resultant data are rescaled and plotted onto the population-history graph, and times of poor climate and reducing population are shown to correlate with significant changes in arrowhead technology.

The most probable evolutionary scenario for technological change in the arrowhead assemblage is then proposed in terms of both endogenous population and technological histories. These supports the dual inheritance perspective that is proposed in chapter two (Boyd and Richerson 1985). In this case, differential social learning strategies subject to drift processes and exogenous environmental constraints, such as fluctuating environments, can ultimately be explained in terms of fluctuating climatic forcing mechanisms (see below).

6.2 Arrowhead variation and faunal data

The phase-level results of arrowhead analysis in the previous chapters are now compared with faunal changes at the same scale, to see if certain shapes of arrowheads can be seen as prey-specific. This helps determine whether certain point shapes may have been functional, and subject to the non-random force of selection. Perhaps the clearest indication of selection is when a population increases after a technological innovation, enabling the environmental carrying capacity to be increased. It is anticipated that the models below will make these variable relationships much clearer.

Before a discussion of the faunal analysis and results, a summation of the relevant results from the previous chapter is necessary, at the time-averaged phase scale. Morphological changes occurs during the earliest Kongemose stages c.6500 Cal BC, stabilises for c.1000 years during the Kongemose phases until 5500 Cal BC, changes again in the SU7 phase c.5400 Cal BC, and finally stabilises c.5200 Cal BC in the Tågerup Ertebølle stage. The chronological model shows that it is likely there is some overlap in these technological traditions, and that they can continue in parallel on occasion, for instance with the probable overlap between SU7 (phase eight) and Tågerup Ertebølle (phase nine) phases. From a combination of the previous chapter's quantitative point-work, and Knarrström's (2003) use-wear analyses, four main changes to arrow-hafting technology can be discerned. Firstly, it appears likely that both Blak II (Phase two) and the earliest part of the Tågerup Kongemose (phase one; see last chapter) had transversely hafted arrows that developed from an earlier tradition. Secondly, a technological change occurred with the main group of six sites (phases one, three, four, five, six and seven) that had obliquely mounted hafting traditions. Thirdly, SU7 (phase eight) apparently had a transitional mix of transverse and obliquely mounted arrows, and fourthly the Tågerup Ertebølle hafting traditions were predominantly transverse.

Because the quantitative results from chapter six demonstrate a high degree of morphological homogeneity, and in some instances use-ware evidence characteristic of high velocity arrowhead technology, it is likely that the excavators' original classifications of the case-study microliths as arrowheads, is correct. Therefore, the time-stepped phase arrowhead data is representative of a particular technological aspect of the bow-arrow system that, at a weapon system level, is stabilised by selection over the period of the case study phases. It follows if arrowhead morphology is not constrained by selection and functional, than in evolutionary terms they must be subject to stochastic drift, within the constraints of the materials used, and the social learning mechanisms used. Under a drift scenario, arrowhead morphology would be constrained only by mechanical requirements of the bow-arrow system to be 'good enough', and subject to population-related innovation and loss effects also at that scale (Neiman 1995; Shennan 2002). So how can we identify drift effects in the case-study arrowheads?

Scale of evolutionary process has been defined as at the phase level for the assemblages, tempo of evolution can be described in broad terms by the chronological model, whilst mode of evolution has been hypothesised as either selection, or a drift related process. To identify the processes more precisely, functional relationships with the faunal remains must be eliminated at the arrowhead trait level, whilst the influence of the selective environment must be accounted for.

A series of statistics were run on the faunal remains data, to help identify different composition of the assemblages that could indicate diet changes, at the time-averaged phase level for each assemblage. Tables of the raw data have been taken from the site reports (Larson 1982; Karsten and Knarrström 2001) and the analyses results can also be found in the **Appendix CD** under the Microsoft Excel spreadsheet; **Ch_6_swedefauna.xls**. Between them, the four phases cover the total chronological range of all nine time-stepped archaeological assemblages used in the Chapter six arrowhead analysis.

6.3 Pie charts

The first model looks at the proportions of mammal, fish, and birds present in the four assemblages, by creating pie charts that show the proportional distributions of absolute numbers of identifiable specimens (NISP) in percentages. Analyses solely using NISP studies can be problematic (Grayson 1984), but the consequent construction of Minimum Number of Individuals (MNI) counts may be heavily biased as a result of taphonomic loss (Blankholm 1994, 48). MNI data is therefore not used here. This study assumes taphonomic processes are either accounted for (Eriksson and Magnell, 2001, 205), or not necessarily problematic, when intra-phase data are compared at certain time averaged scales (Grayson and Delpech 1998). When the total NISP for all four phases were plotted, identical proportions of fish and mammals were found in the Tågerup Kongemose **fig. 6.1**, (phase 1), and Tågerup Ertebølle **fig. 6.4**, (phase 9). This result contradicts the findings of the original analysts Eriksson and Magnell (2001, 205), who claimed a much higher proportion of fish at 81.4% for phase 9 (their phase III), and consequently a much stronger element of fish in the diet during the Ertebølle period. The proportion of fish in the later assemblage was at 81.4% for phase 9 (Eriksson and Magnell 2001, 206; fig. 20). It seems the original analysts conflated the two sets of NISP figures, as the output produces confusingly identical percentage values, so the published pie charts were erroneously constructed. If the relative NISP totals were displayed on the original pie charts, this problem would have been easily spotted and avoided (Shennan 1997, 23). The revised results now show the percentages and the number of specimens per category, and demonstrate the same proportion of fish specimens (55%) to mammal specimens (44%), in both the Kongemose and Ertebølle phases (**fig. 6.1; fig. 6.4**).

In the original osteological analysis measurements, the $\delta^{13}C$ ‰ values from two human individuals and the five domesticated dog sample results were more positive than -17 ‰, which was thought to demonstrate that diet was 'overwhelmingly terrestrial', in the earlier Kongemose phase one, at Tågerup (Eriksson and Magnell, 2001, 207 fig. 21). Segebro, (phase 6) yielded many more mammal remains than the Tågerup phases at 81%, whilst SU7 yielded only 18 fish specimens giving that site a 91% proportion of mammals. Although SU7 remains are limited in their extent, this may not be just chance, (contra Eriksson and Magnell 2001, 217); however, the reduced number of osteological remains does make it analytically problematic.

The results show that in the Tågerup phases where there are later transverse arrowhead traditions (phase 9) and earlier oblique traditions (phase 1), there is no difference between the proportions of fish to mammals. If NISP proportions are a good proxy for diet, and assuming constant numbers of available prey, this indicates that arrowheads do not change shape because of changes in absolute numbers of prey-species.

6.4 NISP/NTAXA ratios

The second model used here is slightly more complex, and was developed by Grayson and Delpech (1998), who originally constructed it to circumvent some of the many problems in constructing diet breadth in foraging theory approaches. Using data from the Early Upper Palaeolithic of south-western France, the relationships between NISP and NTAXA were again explored. Noting the effects of time averaging and differential time sampling on assemblages, the authors found that different relationships in NTAX/NISP ratios could indicate more than just different specimen fragmentation (by Grayson and Delpech 1998, 1124); rather, the entire pattern most probably reflected changing maximum diet breadths through time. This study assumes that differences in NISP-NTAXA relationships are not due to differential fragmentation of bone specimens (Lyman 1994), which can be determined and accounted for through analysis of the ratio of proximal and distal ends to all shafts from all long bones and ribs. A greater degree of fragmentation will differentially increase the number of shaft fragments in this ratio (Grayson and Delpech 1998, 1124); however, detailed examination of the faunal remains is beyond the scope of this project. In a tentative attempt at approximating the diet breadth, a low degree of fragmentation was assumed in the assemblages here, as the original osteological analysts, Eriksson and Magnell for Tågerup (2001) phases, and Lepiksaar (1982) for Segebro, also noted bone fragmentation was not problematic, as they inferred the minimum number of individuals (MNI) from their data. The results are shown in **fig. 6.5**, and **fig. 6.6**, and are used here as a proxy for total diet breadth in the assemblage. These results show a reasonably good linear fit, although the low number of data points makes this difficult to say with certainty. **Fig. 6.5** was used to produce a diet breadth proxy for just the ungulates NTAXA and NISP data. Again, this graph shows a reasonable linear correlation between the log number NTAXA against NISP count, in the four assemblages. Following Grayson and Delpech (1998, 1128) this would indicate a similar diet breadth through time. From these time-averaged results, changing arrow shape, and differential hafting mechanism does not appear to affect case study diet breadth, although more data from the other five unpublished osteological assemblages would be highly desirable, to test this hypothesis further.

6.5 Correspondence analysis

The final statistical technique used for analysing faunal distributions is correspondence analysis (CA). This is a multivariate data reduction technique, which can be described as principal components analysis (PCA) for tables of counts (Shennan 1997, 308). This multivariate technique enables a clear graphical representation of the structure of a table of counts. CA captures the most important variation onto the principal axes in an orthogonal vector space that is a linear transformation of the original data. The approach here uses symmetrical analyses, which means the variables and units can be plotted and compared on the same principle axes. The results can then be interpreted in relation with one another in terms of relative proximity on the graphic output, so units with small sample sizes can be included in the output, without altering the overall structure of the analysis (Shennan 1997, 308; Baxter 2003, 137; Madsen 1988; Johansen 2004, 43). This makes CA ideal for exploratory analysis of count data such as faunal remains, as time sensitive patterns often manifest themselves very clearly, for instance with the horse shoe shaped curves that can aid in seriation of artefacts within and between assemblages. This is a technique that has been extensively applied in Danish archaeological contexts (Madsen 1988; Blankholm 1994; Johansen 2004). Blankholm's method was to use CA as an exploratory technique to highlight interesting and useful patterns between variables that may indicate economic relationship between and within sites, with different preservation conditions. Blankholm preferred using CA instead of taphonomic flow charts, because he thought CA was equally valid, and far clearer to read (Blankholm 1994, 116). However, the resultant CA output will still be viewed with caution here, as a detailed comparison of individual phase taphonomy is beyond the scope of this current project, and specific taphonomic problems may skew final interpretations. The approach taken here is to examine the relationships between different taxa and NISP data, to account for intra- and inter-site time averaged data variation. Species common to all sites will be weighted towards the centre of the output graph, whilst species with a site-specific relationship will be distributed away from a central common cluster in the final output. The symmetrical method used allows the sites (in red) to be on the same graph as the faunal distributions, for easy comparison of spatial relationships.

A series of CA runs using the CANOCO program with different combinations of faunal species were used to explore the data, namely with runs using only fish, mammals and ungulates, and combinations thereof. The raw data, analysis and tabular output can be seen in **Ch_6_swedefauna.xls**, whilst the graphic results can be seen in figures **6.7 and 6.8**, respectively.

Fig. 6.7 shows the graphical output of an unlogged and symmetrical CA for all species across the four case study sites. Despite the number of species including mammals, fish and birds, and the differences between data between the assemblages, several patterns emerge. wild pig, roe deer and red deer appear close to the centre of the axes, as expected because they comprise the bulk of the osteological remains found at the sites, whilst certain species have more site-specific distribution. The chronologically latest phase, Tågerup Ertebølle (phase 9) is clearly associated with small fur bearing animals, which could be indicative of trapping strategies, or of intrusive scavenging species in the settlement/refuse layers, as the Ertebølle refuse layers appear mixed in with the settlement. On the evidence of disarticulation and cut-marks, the Tågerup analysts prefer the former explanation (Eriksson and Magnell 2001, 217), so it seems the faunal evidence supports a switch in economic strategies, from the Kongemose to the Ertebølle phases, perhaps indicating trade with neighbouring or more distant groups. Segebro (phase 6) has a great deal of fish and seal remains, and all phases seem to have site specific species that may indicate specific spatiotemporal ecological niches exploited using a variety of prey capture strategies, as the remains of various contemporaneous complex technological traditions demonstrate (see chapter four).

Another CA was run, without the fish and bird data, as ethnographic evidence indicates that stone tipped points are usually associated with hunting large mammals (Ellis 1997). The results were very clear (see **fig. 6. 8**). The large ungulates – red deer, roe deer and wild pig were positioned at the centre of the principal axis, indicating a constant and important economic role through time. The distribution of pinnipeds is skewed towards Segebro (phase six). The distribution of smaller fur bearing game again clustered again around the later phase of Tågerup Ertebølle (phase nine). The increase in small fur bearing mammals in the later phase may be important in terms of indicating human population increases in terms of widening diet breadth, however, they could be equally indicative of specialisation of hunting, perhaps for trade purposes. Interestingly, models derived from foraging theory suggest high ranked prey, in terms of net calories obtained per unit time spent, will become depressed (less likely to be encountered) relative to low ranked prey as human predation intensifies (Lyman 2003a, 376). This may have resulted in a widening of diet breadth, and a more expedient use of bow-arrow technology. Whether this is the causal mechanism for technological change in the case study assemblages is doubtful, as the above analysis of potential diet breadth indicate similar through time proportions of large ungulates, notably with little change in proportions between Tågerup (phase one) and Tågerup Ertebølle (phase nine). Interestingly, the relationship between SU7 (phase eight), and Tågerup Kongemose (phase one) is closer than between SU7 (phase eight) and Tågerup Ertebølle (Phase nine). However, SU7 (phase eight) has less faunal remains than the other sites, whilst large ungulates still predominate throughout. In terms of the difference in projectile shape, SU7 is much closer to Tågerup Ertebølle in terms of common point morphological characteristics (see **fig. 5.42**). In conjunction with the above results, this is taken as further evidence that projectile point morphology is not functionally related to prey-specific bow-hunting, or diet-breadth widening in the case study.

According to Friss-Hansen's (1990) cutting index (CI), the central Kongemose phase-group's cutting arrowheads are likely to be near the engineering optimal for hunting large ungulates, compared to the lower CI that was calculated for transverse arrowheads. The Tågerup Ertebølle (phase 9) points are likely to be near the optimum for transverse arrowheads, as their mean key dimensions are closely grouped (see **fig. 5. 42**). The Blak II (phase 2), and SU7 (phase 8) arrowheads are likely to be away from the optimal value for transverse arrowheads, whilst the Blak II (phase 2), SU7 (phase 8) are likely to be further away from the optimal CI value for transverse arrowheads, as their mean key dimensions are more variable (See **fig. 5.42**). The above faunal analysis shows the continuing centrality of large ungulates in the diet, so changes to point shape are apparently not the result of directional selection. Functional-adaptative responses are effectively eliminated as the evolutionary mechanism directly responsible case study arrow head morphology.

6.6 Population model

The effect of natural selection can be directly measured through the success and failure of populations – the ultimate criterion of selection is reproductive success (Kirch 1982; Paine 1997a, 1997b). The adaptative role of technology at a population level of analysis is not always a simple one, as the effect on any given population may be variable and requires careful evaluation (see chapter two; Steiner et al. 2000). Nonetheless understanding long-term population dynamics is vital to understanding cultural change on all scales of analysis, and this requires much more consideration than it currently receives.

Henrich's recent study used qualitative Tasmanian data to show that a sudden drop in the effective population size (the size of the interacting pool of social learners; see chapter two) and loss of complex technologies, was causally linked to early Holocene climate changes (Henrich 2004, 197). Henrich proposed that a reduction in interacting social learners generated maladaptive losses in more complex technological knowledge concerning fishing, whilst some simpler lithic technologies actually became more complex, as the sea levels rose around Tasmania. In Henrich's multi-scaled model, selection acted directly against the genetic population, whilst differential cultural transmission rates could account for the complex changes in technology that were evident in the archaeological record (Henrich 2004, 209). Although convincing in his formal modeling and general explanation, Henrich did not explicitly link the hard data of population levels and climate fluctuations to details of technological change; the supporting archaeological evidence was only described in broad qualitative terms.

In this section fluctuating human population levels are modelled for the case study region and chronological period. The method developed here combines the available calibrated ^{14}C data, into a graph that is then taken as a proxy for demographic fluctuations through time. All the raw data and associated references can be found in the accompanying CD, Excel file under **Ch_4_kongdates.xls,** in the '**master dates**' and '**population models**' spreadsheet.

The population model constructed here is a refined version of the method recently used by Gkiasta (et al 2003), that uses a Bayesian OxCal model. In Gkiatsa's model of European ^{14}C data that helped track the spread of farming, the OxCal **Sum** command was used to obtain a time averaged calibrated probability distribution, combining all the available ^{14}C data. This may prove a problematic technique, as the resultant distributions may be skewed by certain sites that have a disproportionate amount of ^{14}C data. 317 ^{14}C distributions were input, from 49 sites across the final Maglemose, Kongemose and Ertebølle cultural phases. The raw data was entered into OxCal using the Sum command, and a probability distribution was calculated. The number of available dates were found to affect both the position of the distribution, and steepness of spikes. Although broad chronological correlations were found with the earlier detailed models from Chapter 5, e.g., that the 'crash' at 5400 BC coincides with the site Tågerup (phase 1) Boundary End distribution in **fig. 4.12**, this model was not accepted.

For the case study data, a different OxCal model was developed, where each archaeological phase containing published ^{14}C dates throughout the South Scandinavian Mesolithic (n. 352 dates) was averaged using both the **R_Combine** and the **Sum** function, which also calibrates the radiocarbon results. The **R_Combine** command produced a single representative date for each site's occupation horizon (n. 58 dates). The resultant data for each site can be found in the accompanying CD Excel file **Ch_4g_kongdates.xls,** in the **population models** spreadsheet. Each of these time-averaged phase dates were then combined using the **Sum** function in OxCal, to produce a time-averaged probability distribution. This final distribution is hypothesized here to represent fluctuating population in calibrated radiocarbon years. This final model successfully accounted for the different numbers of dates from the different phases, by only using one time-averaged distribution from each.

The final population-proxy model (see below) provides a falsifiable hypothesis one that is calibrated and calendar dated, and one that can provide a solid baseline for the clear understanding of general population dynamics in the case-study area. As the radiometric data is taken from all samples relating to the *occupation phases* boundaries and from data therein for sound stratigraphic reasons, it is reasonable to argue that the chronological hypotheses subsequently generated are reasonably accurate, if not always totally precise. More precision could be gained by further vetting each sample for appropriateness in its individual stratigraphic context, as was done for the earlier phase model (**fig. 4.12**). For the purposes of this thesis, this is not considered problematic, as earlier comparison of regional Bayesian models throughout the model construction process demonstrated that the *gaps* in the final output distributions – representing population crashes - did not vary significantly, despite some fluctuation in the probability peaks elsewhere. The significance of each population hiatus will be explained in chapter seven. However, for even more chronological precision, it would naturally be desirable to create an entire regional phase model along the lines of **fig. 4.12**, for all occupation phases in the region, and although this is beyond the scope of this thesis, it would provide a highly productive avenue for future regionally expanded research.

The reason why Gkiatsa's (2003) OxCal **Sum** model was further refined here, was to control for large well funded sites such as Tågerup that had high numbers of radiometric results, results that could potentially skew the final chronological interpretations. It is argued that the use of **R_Combine**, used here to combine *each* occupation phase in turn - rather than all phases at once with the **Sum** command – successfully circumnavigates this problem.

The results were very interesting (see **fig. 6.9**), and require cross-referencing with the original Bayesian nine phase model from chapter five (see **fig. 4.12, 4.13**). The four major divisions of peaks in the graph were seen as representing the populations of the traditionally named final Maglemose, Blak, Kongemose and Ertebølle phases. The period at 6400 Cal BC shows a gap in the data that signals a population crash at the end of the Maglemose, just prior to the beginning of the 'Middle Mesolithic' phases. The period that is shown to begin just after 6000 Cal BC sees a crash after the 'Blak phase' period, which can be seen to dip just at the start of the 'Kongemose phase' at 5700 Cal BC. The complex punched blade and micro-burin technology continues into the Blak phase, although the graph suggests a very low population in the interim period between the Maglemose and the Blak phase. This reduction in population may explain the change in hafting tradition from the earlier more complex oblique hafting traditions, as the pool of interacting social learners was considerably reduced.

Stasis in complex indirect punched blade technology associated with the Blak and Kongemose phases is remarkably long, and remains throughout the Tågerup phases for c. 1200 years, as demonstrated by the main group of six phases by their clustering mean confidence ellipse (see **fig. 5.12**). However, at the same time, there is a radical switch in hafting traditions, from transverse in the Blak phase, to oblique hafting throughout the Kongemose phases. In population terms, following the graph at c.5700 Cal BC this switch to the more complex oblique hafting technology may have been precipitated by a population increase, with an effective increase in the pool of interacting social learners. The subsequent technological stasis throughout the Kongemose phases seems to be due to the generally stable nature of the population - indicated at this time by **fig. 6.9.** This remarkable homogeneity of tradition may be due to highly constrained social learning modes, fixing indirect biased technological transmission mechanisms in the population. In effect, the hunting techniques appear to be largely successful and highly specialized, but perhaps inflexible (see Eriksson and Magnell 2001, 199, fig. 17). At the end of the Kongemose phase, a change in technology could have been prompted by fluctuating environmental conditions. As Fitzhugh suggests, people are more likely to experiment with new technologies when they are in a risky situation, and when have little to lose by doing so. This possibility will be tested below.

The change in arrowhead hafting from oblique in Kongemose to transverse in SU7 (Phase 8), which is completed during Tågerup Ertebølle (phase 9), is preceded by a rapid population drop c.5000 BC, which may precipitate the associated change to a simpler lithic reduction strategy of predominantly direct percussion throughout the Ertebølle. The overlapping start end boundary distributions between the Tågerup phases, and at SU7 (see **fig. 4.12**), indicate a continuation of population in the area rather than any sudden replacement. Again, a near reduction of the evidence for previous complex indirect blade technologies suggests the possibility of drop in the population, as technologies become increasingly likely to be lost as there are less people transmitting it to the next generation. The rapid spread and ubiquity of the transverse arrowhead in the Ertebølle could be attributed to its fixation in a small effective transmitting population, in the same way that was modeled by Neiman for pottery traditions elsewhere (Neiman 1995). Evidence for changing point technology and faunal distributions indicate no relationship between point shape and changing diet breadth, or prey capture strategy between Kongemose and the Early Ertebølle period at Tågerup (see above). From mortuary evidence, Meikeljohn et al. note that there may be steady but low population growth through the Kongemose and earlier Ertebølle periods but no evidence for rapid growth in the latest part of the Mesolithic prior to the Neolithic transition. As this pattern seems peculiar to the region (Meiklejohn et al. 1997, 321) this is an assumption that requires further testing. It is possible that a loss of land, due to land rebound and eustatic sea rise, could have increased population density, as less land was available due to the encroaching North Sea (Meikeljohn et al. 1997, 322). An expansion of the OxCal population model into the Scandinavian Neolithic may shed light on this problem, abut is currently beyond the scope of this thesis. Reduction in land will be modeled below, to determine if this was likely to have been a significant factor for the local populations.

The Ertebølle culture is seen to crash around 4000 BC, when the population is seen to dip sharply. It is widely agreed that there was intense intra- and inter-group competition in this period of the final Mesolithic, as there is evidence for steadily increased population levels with more Ertebølle settlements, coupled with increased evidence for skeletal trauma, and an apparently deliberate avoidance of adoption of the full Neolithic package for several hundreds of years later than the neighboring regions (Price 1991). It is a possibility that the people of the Ertebølle period were simply out reproduced by the farmers, thanks to different life history strategies, fertility rates, and differential methods of resource provisioning in times of environmental fluctuation and population density. It appears that the Ertebølle peoples had a good equivalent to the farming adaptations, with their use of marine resources, demonstrated by the ubiquitous shell middens. If crucial marine resources were adversely affected by environmental/climatic fluctuation, there would be more reason for the local people to adopt more elements of the Neolithic farming package. However, the question remains as to the precise mechanisms affecting the case study populations.

6.7 Causal reasons for population fluctuation in the case study.

This section presents three hypotheses for the population fluctuations proposed in section 6.6 above, for the south Scandinavian Mesolithic case study. They are all ultimately climate related in some way, but the precise causal relationship requires closer examination.

Hypothesis 1.

Loss of habitation area for humans and animals due to land reduction forced by sea level changes causes population fluctuations.

The evidence is clear that there was a significant increase in precipitation in the case study region due to the retreating ice sheets after the last glacial maximum (see chapter four). There is also significant land rebound (isostatic uplift) that can affect the accuracy of interpretations of relative sea level rises, these can vary dramatically on a local and regional scale (Christensen 1995). The total period of the case study (c.9000- 5000 BP) sees a complex combination of ingression, regression, and transgression horizons that are the subject of much current debate, and one often avoided by geologists as the previous period, up to the Younger Dryas, is much easier to account for (Björk 1995).

The continuing post-glacial processes that led to the modern island landscape of Denmark and southern Sweden was not one of straightforward land inundation and reduction of landmass and is consequently very difficult to quantify (Christensen 1995; Karsten and Knarrström 2003). The period is not only characterized by loss of habitats, as many ecologically diverse and resource rich niches were created simultaneously. In general terms, swamps and marshes both yield a higher amount of resources than woodland (Rowley Conwy 1983, 118, table 10.2). To examine the impact of reducing land mass, following Maroo and Yalden (2000), a the relative numbers of large ungulates and humans were quantified for a Mesolithic landscape that was characterized by a hypothetical reduction in landmass scaled from 0-20% in five 5% stages (**fig. 6.10**). Assuming the landmass and ecological niche composition of the area of south Scandinavia was constant and analogous to that calculated for 220, 111km^2 of Great Britain without Shetland Orkney or the Outer Hebrides c. 7000 BP by Maroo and Yalden, a reasonable estimate of absolute and relative numbers of large ungulates to human ratios can be calculated. Maroo and Yalden based their calculations Mesolithic mammal numbers mainly on the fauna of the Białowieża National Park in Poland for the Ungulates, Lynx and Wolf numbers (Jędrzejewski 1998). These are estimates of living populations, and it seems quite possible that there were more predators such as wolves in prehistory, as the National Park is still an artificial environment to a degree.

As the important issue is the relative numbers of prehistoric ungulates to humans, the model had to accommodate the different estimates of human Mesolithic populations, which is disputed by different demographers (Karsten and Knarrström 2003, 212). The solution was to include all the different estimates for human density in the case study region in the model. The human density figures used here were taken from Kelly 1995 (tab. 6-4), and range from recent estimates of hunter gatherer populations of 0.013-0.38 inhabitants per km^2 to estimates from the US North West Coast of between 2-4 people per km^2. It is proposed that the higher end of the population density figures is appropriate for parts of Scandinavia during the case study period (Karsten and Knarrström 2003, 212-213). Although the model presented here is a gross simplification, the land mass of contemporaneous south Scandinavia (Sørensen 1996) is broadly comparable to Great Britain in both size, climate and flora throughout the climatic optimum, prior to the elm decline around 5000 BP. Localized processes of isostatic uplift and eustatic sea rise are highly complex (Christensen 1995), but its is posited that the overall reduction in available land mass (at an average of 2.5 cm per year from 6000 Cal BC to 4000 Cal BP), fodder, and large ungulates in low level Southern Scandinavia (ibid.), is offset by the increased number of estuaries and the generally increasing evidence of estuarine resource exploitation adaptations by the local population characterized by the relatively diverse Ertebølle period subsistence technologies (Price 1995).

Even in the worst case estimate of a 20% land mass reduction during the case study period, the results show that the high ranking resources seem to easily accommodate the requirements of even the largest estimated human population, assuming stable and constant proportions through time (**fig. 6.10**). This estimate fits with the possibility that the region was divided into territories by a largely sedentary population. However, to examine these estimations more satisfactorily, it would be necessarily to model changes in densities in relation to more dynamic life-history scenarios (Hill and Hurtado 1996), and more abrupt and punctuated climatic changes (see below), as even the non-human animals in question reproduce at different rates and recover from different environmental stresses often in a counter-intuitive manner. This is a current area of research for the Large Animal Research Group at Cambridge, with their comparative studies of red deer and Soay Sheep on the Hebridean islands; this has proved a complex system even over a thirty year period (Clutton-Brock 2002, 1285).

It appears even a drastic reduction in land mass still allows a sufficient large number of ungulates for humans to draw upon, as their numbers are higher than the combined human population in all cases, with all ecological factors remaining equal. Humans remain outnumbered by just ungulates at each 5% time step even at the highest proposed population density, even when other marine resources are not factored into the analysis. It seems likely that new marsh and estuarine environments would provide even greater carrying capacity than previously, assuming the local population is only slightly flexible in their prey-capture strategies. As the diet proportions are seen as constant between the Tågerup Kongemose (phase 1) and Ertebølle Phases (phase 9), it is concluded that this hypothesis 1 does not hold true.

Hypothesis 2.

Long term natural or anthropogenic changes to habitats caused population fluctuations in the period of the case study

It is clear that after the Pleistocene/Holocene boundary, from ca. 9 Ka BP to the start of the Elm decline 5 Ka BP, there are no significant long term broad scale patterns of forestation or deforestation discernable from the pollen record that are likely to effect population levels (Larsson 1983; Huntley and Birks 1983; Karsten and Knarrström 2003). This is despite earlier drastic post glacial changes in flora and fauna related to temperature rises inferred from isotopic evidence (see below).

At a broad scale, this period is characterized by mixed forests, and is termed the 'climatic optimum' by climatologists (see below). It is also termed the Mesocratic stage of the interglacial cycle. The post glacial establishment of a variety of temperate deciduous trees forming dense woodland is a relatively rapid process that sees migrations of certain tree species, but does not affect the area of woodland to a significant degree, once the forests are established (Bell and Walker 1992).

The duration of the case study from Blak phases through to the Early Ertebølle sees little evidence of anthropogenic affects on the forest, other than a possibility of limited ring barking at Tågerup in the Early Ertebølle (phase 9) which indicates possible coppicing which the excavators think is done to promote the growth of a Hazel, and a limited number of other species (see chapter three). The proportion of forest to meadow, which affects the availability of ungulate fodder (Clutton-Brock et al. 2002) is therefore not deemed significant throughout the case study period. Hypothesis 2 is therefore discounted.

Hypothesis 3.
Short term climatic changes inferred by isotope proxies directly effect the environment causing population fluctuations.

Isotope evidence has increasingly been used as an environmental proxy, and the fine grained Holocene data is particularly well suited to this method (Shennan 2003b). Residual $\Delta\,^{14}C$ isotope ratio measured in parts per million (ppm) from tree rings have been used to indicate the variation in the ^{14}C content in the atmosphere (Stuiver M. and Reimer P., 1993). This data can be plotted and compared with archaeological data to infer periods of climatic deterioration and amelioration (Shennan 2002, fig. 26). Low concentrations of ^{14}C reflect high levels of solar activity; high levels indicate low levels of solar activity. Compared with Historical data, for instance from the Little Ice Age 16th -18th centuries AD, isotope evidence supports the idea that low levels of solar activity can result in relatively short, wet, and colder summers (Fisher and Koerner 2003). The result is that cooler, wetter weather would be unfavorable to the human food chain, and would directly affect local resources, and ultimately the carrying capacity of the environment – increased mortality would result (Maise 1998); but more importantly, reduced fertility rates would occur, this is proposed as the key factor that can rapidly decimate a population over a few generations. However, if this climatic process was detrimentally affecting geographically circumscribed prehistoric groups, for instance when surrounding ecological patches were occupied in southern Scandinavian Mesolithic, it is reasonable to assume resource competition-stress could trigger a population crash, and a fluctuating demographic pattern would be the long term result.

It appears recent Oxygen isotope data may help support the $\Delta\,^{14}C$ isotope evidence. Recently, Oxygen isotope variations derived from six Greenland sites by paleoclimatologists have demonstrated some strong similarities. These are the cores from Camp Century, Dye-3, GRIP, GISP2, Renland and North GRIP. It is highly likely that the major influence on these regional fluctuations was regional climatic change, whilst optimum Holocene temperatures were achieved 8.6-4.3 thousand years ago (Johnsen *et al.* 2001, 99). Through modeled inversion of the bore hole temperature constrained by either the dated isotope profile, or by Monte Carlo simulation techniques, palaeotemperatures have now been estimated with consistent results (Johnson *ibid.*). The cross referenced isotope data shows that a marked cold event, known as the '8.2 ka event', is clearly indicated. This event falls at the beginning of the Kongemose phases as, demonstrated by the by the case-study Bayesian phase chronology in chapter four.

A diagram (**fig. 6.11**) was constructed using the 'freeware' CalPal program to examine possible causal relationships between population fluctuations and two proxies for Holocene environmental changes. The upper plot in red shows $\delta^{18}O/\ \delta^{16}O$ isotope ratio data taken from Greenland ice core GISP2 (Bond et al. 2001, 2132), which is taken here as a general proxy for the amount of climatic precipitation and temperature, where a trough indicates more precipitation and cooler conditions (Grootes et al. 1993; Meese et al. 1994; Stuiver et al. 1993; Sowers et al. 1993). The lower plot in blue is the residual $\Delta\,^{14}C$ isotope ratio (Stuiver M. and Reimer P., 1993). This is taken as a proxy for temperature change, where a trough in the plot indicates warmer conditions, as negative values are correlated with more solar activity (see Shennan 2002, 132). These environmental proxies were superimposed onto the population hypothesis plot (**Fig 6.12**). The X axis is presented in calibrated calendar years BP. The results demonstrated an interesting correlation between climate and demographic proxies.

It is argued that, although the correlation between climatic and population proxies is not great, the CalPal method of climate proxy construction used here currently provides the most accurate way of representing chronologically synchronised paleo-climatic change in terms of the case-study region data. It should be noted that the relationship between the isotope curves and actual prehistoric climate fluctuations continue to be the subject of heated date between paleoclimatologists (see Johnsen et al. 2001), but at the present time of writing, these curves undoubtedly provide an excellent working hypothesis for the technological purposes of this thesis. It is hoped that further refinements to both the proxy climate curves, and the radiometric population model presented here will ultimately produce a more precise correlation, as more climatically accurate proxy data, and more accurate radiometric data becomes available in the future.

Note on **fig. 6.12**, a population trough at 8300 BP coincides with a big dip in the upper red $\delta^{18}O$ curve, and a slight rise in the lower blue $\Delta\ ^{14}C$ plot. This is taken as the '8.2 ka event', interpreted here as a relatively cold and wet period, unfavorable for the mammalian food chain. The following period sees an increase in temperature and is seen as an increasingly drier period, which corresponds with a dramatic increase in population. The population trough at around 7000 BP occurs during another relatively cold period following the relatively high $\Delta\ ^{14}C$ value, whilst the $\delta^{18}O$ plot appears to trend down at the same time, again indicating a cooler period.

It is proposed here that if environmental conditions fluctuate too far from an optimum for the human food chain when a population is near carrying capacity, a population crash may result (Shennan 2002). Conversely, in very general terms, population growth may occur when the optimum period is maintained, and the environment is more predictable. However, the ecological complexities have to be accounted for on a case by case basis. For instance, where the data does not correspond to the broad expectations, perhaps a greater diversity of technologies, or perhaps new or more efficient technological adaptations, may help explain a high population, when it is least expected. in the terms of the case study period, there appears to be some interesting correlations between climatic degradation, and population collapse. Whether or not this is the case for the first farmers in the area, is another potential avenue for future research.

In conclusion, a fine grained comparison of environmental change using the isotope evidence as proxies is seen to hold the most explanatory power, and therefore hypothesis 3 remains to be falsified.

6.8 Summary of results

This chapter has examined the time averaged arrowhead data chapter five, in terms of the fluctuating selective environment of the data itself. A population level approach has been adopted which accounts for technological changes seen in the arrow head assemblages in terms of specific evolutionary processes.

Time averaged faunal evidence has been analyzed for variation, to enable a meaningful comparison with the contemporaneous point data. The pie-chart analysis demonstrated no significant through-time trend in the faunal data that could correlate with changes in point data, as Segebro (phase 6) and Tågerup Kongemose (phase 1) showed different proportions of ungulates, whilst the later Tågerup Ertebølle (phase 9) showed an identical proportion of ungulates as the earlier Tågerup Kongemose (phase 1) phase. The NISP/NTAXA diet-breadth method following Grayson and Delpech's 1998 method also showed no significant variation in inferred diet-breadth between assemblages, although data from more faunal assemblages for the other case study phases would be very useful for a broader comparison of other phase data. The correspondence analysis demonstrated that large ungulates, ideally hunted with the Kongemose type of oblique slashing arrows (Friss-Hansen 1990) dominated all four assemblages, as they were close to the center of the axis of the two major functions. Again, no significant change was seen between the Tågerup Kongemose (phase 1) and the Tågerup Ertebølle (phase 9) distribution of ungulates in this instance.

Although other studies such as Hughes (1998) suggest that selection can act strongly at the weapon system scale, it was concluded that there was no functional relationship between arrowhead morphology and the faunal assemblages at the phase level of analysis here. As selection was not seen to constrain technological traits at the scale of the arrowhead, an alternative drift-related explanation was explored in terms of demography.

Diachronic population fluctuations were then modeled for the case study region. The OxCal package was used to average the radiocarbon distributions, using the south Scandinavian 14C data as a population proxy. The calibrated distribution of occupation horizons in the South Scandinavian Mesolithic was approximated using the **R_Combine** and **Sum** commands in a modification of Gkiasta's (et al. 2003) method. A close correlation was found between changes in lithic reduction strategies, and inferred changes in population levels. It is argued here that drift processes can explain these changes, as loss of effective teachers and students involved in the transmission of complex technological traditions, such as the indirect punched blade and microburin techniques (Knarrström 2001) associated with the Segebro (phase 6) and Tågerup Kongemose (phase 1) phases were more likely to be lost when there are suddenly less people in the transmitting population. Similarly, less complex traits and techniques, such as direct percussion blade technologies (Knarrström 2001) are likely to become fixed in a small population through drift, following Neiman's simulation, and Henrich's more recent formal models of cultural transmission (Neiman 1995; Shennan 2002; Henrich 2004).

The final part of this chapter presents and tests three hypotheses that could causally explain the proposed population fluctuations. Hypothesis one proposed that land mass reduction decimated faunal populations to a degree where they could no longer support the local human populations, precipitating the population crashes, as the sea level generally rose throughout the period of the case study. This hypothesis was disproved as the ungulate numbers alone were shown to greatly outnumber all the current estimates of different densities of human populations, even when they were high. The local populations also had a significant amount of marine based resources which they exploited throughout, in all the above four phases. Mesolithic mammalian population density estimates for south Scandinavia were simply derived from the modem estimates by Maroo and Yalden (2001), and transposed the corresponding mammalian densities of Białowieża National Park in Poland onto the 222, 000 km^2 landmass of Britain (2001). Assuming a constant rate of environmental change, human populations were unlikely to be significantly affected by landmass reduction, as increasing numbers of wetland marshes and new estuaries subsequently created would have presented even more productive patches than the extant deciduous forests (Rowley Conwy 1983). Human populations were shown to be independent of increased geographic circumscription, in the case study.

The second hypothesis was that natural or anthropogenic changes to habitats causing population fluctuations in the period of the case study. It seems reasonable that Potential deforestation and forestation throughout the period would have significantly affected human populations. Again this was shown to be incorrect as the available pollen statistical evidence does not indicate significant horizons of change in the case study period.

The third hypotheses was that short term climatic changes, inferred by $\Delta^{14}C$ and $\delta^{18}O$ isotope climate proxies, directly effected the case study environment, for example by affecting the reproductive success of prey animals (see Clutton-Brock 2002) causing the population fluctuations that were previously graphed. When the isotope data was rescaled and plotted onto the population graph, a correlation was found between inferred periods of climatic degradation, and periods of population reduction. The effects of the widely understood '8.2 ka event' are particularly noticeable (see above), as was the clear climatic correlation with the population trough at c.7000 BP. On the basis of the available climate proxy evidence, this hypothesis remains to be falsified, and is the most likely casual reason for the case study population fluctuation. The time averaged changes to arrowhead morphology can therefore be causally linked to climate, population level, and resultant drift processes, rather than the selection acting directly on point traits.

Chapter 7: Conclusions

This thesis has developed and applied a new integrated evolutionary program of archaeological research in a largely unprecedented manner. In a significant advance on recent theory-laden evolutionary methodologies that promise much (see Boone and Smith 1998 criticisms of evolutionary archaeology), the models developed here use an exceptionally well contextualised archaeological dataset. This has resulted not only in substantive advances in the understanding of the southern Scandinavian Mesolithic, but has a more profound implication for the role of archaeology within the wider body of the social sciences. If archaeology is to avoid becoming an intellectually sidelined discipline, one that is purely responsive to developments in the other social sciences, or worse still, just an irrelevant curiosity; the explanatory power of testing evolutionary models in terms of the long-term material record has to be exploited to its full potential. It is hoped that this project initiates a cumulative program of evolutionary archaeological research, one that can be extended and expanded, one analysing multiple technological trajectories, not just bow-arrow technology; and one that compares both the results gained from different chronological periods, and those from geographically wider cultural interaction. The specific implications for future research will be discussed below after a brief summary of the results of each chapter.

7.1 Summary of results

In essence, this project developed a theoretical approach that avoided simplistic assumptions about the mode, tempo, scale, and direction of technological evolution. Chapter one introduced the thesis, and examined the history of technological and evolutionary theory. From the beginnings of the western traditions, those embodied by Hesiod's pessimistic technological 'descent of man', culture and technology have usually been seen as following a single linear developmental trajectory. This view was particularly prevalent in the classical evolutionary perspectives of 'inevitable' technological progress from the nineteenth century, embodied in the writings of Herbert Spencer. The classical evolutionists were found to be overly anthropocentric in their theoretical perspectives, and their erroneous views were seen to adversely influence current social evolutionists. In methodological contrast, it was proposed that nuanced evolutionary approaches, those that accounted for more complex and often counterintuitive Malthusian and Darwinian processes, had a great deal of promise for archaeological research. A brief history of some of these approaches, and their developing relationship with the history of archaeological theory was presented. Recent theoretical developments in the life sciences were shown to be already highly productive in other social sciences, archaeology was shown to be able to make a unique contribution, with its access to the long-term material record. Associated problems and current controversies concerning the identification of the correct scale, mode, and tempo of evolution, was then detailed in terms of specific archaeological examples. Due to the potentially excellent archaeological context available for certain projectile point assemblages, an evolutionary study of the bow-arrow weapon system was found to be long overdue.

Despite a glut of theoretical research published by evolutionary archaeologists (EA) following Dunnell's classic 'style and function' paper (1978), and despite the potential of dual inheritance theory (DIT) presented by Boyd and Richerson with the publication of *Culture and the evolutionary process* (1985), it was shown that the behavioural ecologists (BE, see Smith 1998) had the most productive research program, using optimal foraging theory (OFT). However, archaeology was shown to have a unique position within the social sciences to test a range of powerful 'Darwinian' models using the long term material record, developed by both archaeologists and other disciplines (Shennan 2000, 2003), whilst important theoretical issues remained to be resolved (Smith 1998; O'Brien 1998). The difficult 'units of analysis' issues surrounding Dawkin's meme theory, i.e., where exactly is a meme located, were often circumvented by adopting the *phenotypic gambit* or 'black box' perspective of behavioural ecology. This was not necessarily the best approach for archaeologists to follow, and was shown to be consequently an area of intense debate (O'Brien and Lyman 2000; Aunger 2003). A purely adaptationist approach to technology was critiqued as comparatively crude, following recent breakthroughs in theoretical biology, notably with the development of neutral theory. It was found that Boyd and Richerson's DIT can provide a more nuanced perspective of gene-culture co-evolution that takes account of historical information constraints at the population level, without the need to invoke selection as a direct causal mechanism (Henrich 2004, 207). Although BE and EA approaches enabled a more convincing level of modelling and explanation of cultural phenomena than previous archaeological paradigms allowed, it was proposed that a DIT could have the greatest archaeological potential. Under a DIT paradigm, distinct technological lineages can result solely from differential social learning modes, and from different interaction rates between effective social learners within a population (Bettinger and Eerkens 1999; Henrich 2004). Likewise, as long as population and environment are accounted for, certain technological traits could even be explained as maladaptive. It was shown that maladaptive and selectively neutral traits could also become fixed in a population purely through random drift processes, analogous to neutral genetic evolution (Neiman 1995). Similarly, it was shown that loss of complex technologies, or aspects of complex technologies, were more likely when effective populations were reduced in size, and more prone to random effects, as Rivers discussed in the case of loss of canoe building technology in Oceania (Pitt Rivers 1926, 200; Shennan 2003; Henrich 2004). The chapter was concluded with an examination of DIT related population level effects specifically related to bow-arrow projectile technologies, that could increase and decrease probabilities of technological innovation, and technological stasis, in terms of social learning and drift sorting mechanisms, as well as selection.

Chapter two explained the precise archery terminology and taxonomy, examined previous approaches to bow arrow technology, and presented a 'Darwinian' methodology for the case study material. New and Old World academic approaches to bow-arrow systems were compared. Alternative Near and Far Eastern traditions of studying archery were found to predate those from the West. Most explanations for development of the bow were found to be purely inductive, devoid of theory, and often crude in the level of explanation. Nonetheless, the long-term pan-cultural interest in archery produced a great deal of good empirical information, and some seminal technological studies (Ascham 1545; Pope 1927; Klopsteg 1947; Rausing 1967; Hardy 1976; Bettinger and Eerkens 1999). This data was used to illustrate many qualitative examples of bow technologies that followed multi-linear and reticulating evolutionary trajectories, such as various composite bow technologies. Instances of technological stasis were explained, using the socially constrained Japanese archery traditions. These examples underlined the need for a case by case methodology.

Arrowhead typology was shown to form the backbone of many relative dating techniques, notably for the Scandinavian Mesolithic. A number of excellent functional analyses concerning aspects of bow-arrow technology were shown to occur both before and since the advent of New Archaeology, and some of the technical assumptions made by seriation derived typologies were challenged as a result (Knarrström 2001). Quantitative techniques developed mainly in the US due to the abundance of surface scatters of points, and the continuing interest in the 'first Americans', were shown to have great potential for analysing the composition of Old World projectile point assemblages. Ideally, a case-study would use a chronological framework that was not reliant on typological dating assumptions. It was proposed that as long as they are placed in the context of absolute dating methods, a linked series of statistical techniques would help to distinguish projectile points from different weapon systems (Thomas 1978; Shott 1997). Variation in arrowhead morphological data was shown to provide a great deal of information concerning inherited technological traditions. This variation would be time-averaged, and compared across archaeological phases, prior to a same-scale analysis of faunal remains and environmental constraints, for a productive evolutionary case-study.

Chapter three presented the case study data. The Middle Mesolithic of south Scandinavia was shown to hold great potential for the fine grained analysis of bow-arrow technology, due to the distinguished regional research traditions, and the quantity of well-contextualised data available for analysis. The post-glacial context of the data was presented, as were the previous paradigms for the evolution of arrowheads in the case-study region. The available data from the nine archaeological phases were described in terms of their contrasting amounts of archaeological data. The size and detail of the recent Tågerup promontory excavations were shown to offer a remarkable amount of useful contextualising environmental evidence for the analysis of arrowhead variation.

Chapter four ordered the nine find-bearing phases of the case study, using a Bayesian chronological model. Previous chronological schemes for the region were analysed, and the problems with the relative dating methods and resultant point typologies were explained. The context of the radiometric data from the nine point-bearing phases was detailed on a site by site basis. The modelling facilities of the OxCal calibration package were used to account for the calibrated ^{14}C distributions, which were constrained in terms of the known archaeological context. Each archaeological phase was bounded, and the resultant output displayed the most probable start and finish boundary distributions in calibrated calendar years on the same plot. An accompanying plot displayed the most probable duration of each phase. The point-bearing phases were then time-stepped, so the morphological variation could be calculated and compared on a like for like basis. The sites were found to have different phase durations, from being very short-term occupation of only a few years, in the case of Villingebæk, to c.1200 years in the case of the first Tågerup phase. The disparity in phase durations did not meet the required similar phase duration criteria for frequency seriation (Lipo et al. 1997; O'Brien and Lyman 2000), so the validity of Vang Petersen's typology that used point data from incompatible length phases was questioned.

Chapter five introduced, quantified, and compared the projectile point data from the nine time-stepped archaeological phases. Previous approaches to Scandinavian arrowheads were analysed in terms of extant typology and functional analyses. Use-ware analysis of the earliest Tågerup points which morphologically corresponded to the early Blak II points, indicated a common transverse hafting tradition similar to the later Ertebølle phase, and certainly not a single linear mode of technological development as previously supposed. The bimodal frequency distribution of the angle variable indicated that Blak II, SU7, and Tågerup Ertebølle phases had a different technological tradition than the main Kongemose phase group (phases one, three, four, five, six, and seven; see below). Descriptive and multivariate statistics were used to classify and account for more complex relationships concerning morphological variation. The uniform nature of quantified projectile points indicated they were correctly classified as arrowheads by the excavating archaeologists, and unlikely to have come from other artefact classes. A chronologically central group of six Kongemose phase sites was found to be remarkably morphologically uniform, indicating a common technological and social interaction sphere; one constrained for well over a thousand years. The coefficient of variation demonstrated a consistent angle variable was not in evidence at Blak (Phase two), SU7 (phase eight) and Tågerup Ertebølle (phase nine). This may or may not be due to a prey-specific capture strategy in the main Kongemose group (phases one, three, four, five, six, and seven). Multivariate analysis demonstrated that the Blak II phase was morphologically closer to the SU7 (phase eight) and Tågerup Ertebølle (phase nine) assemblages.

In terms of selection, it was hypothesised that on engineering and experimental grounds (see Friss-Hansen 1990) that the Tågerup Ertebølle (phase nine) group was near a functional optimum for the bow-arrow. SU7 (phase eight) and Blak (phase two) are possibly 'moving' towards the same optimum, due to directional selection (see **fig. 5.42**). Following Friss- Hansen's (1990) functional work, morphological stasis around a mean point in the tightly clustered Kongemose phase group (phases one, three, four, five, six, and seven; see **fig. 5.42**) may be the result of stabilised selection at another optimum. The mean confidence ellipse diagram (see **fig. 5.42**) represented the time averaged variation for the technological traditions using two variables that contain the most amount of information that characterised each assemblage.

Chapter six provided an ecological context for the point data, to enable an evolutionary analysis of the time averaged arrowhead data in terms of the changing selective environment. It initially consisted of a faunal analysis and population model, to determine if the morphological changes in arrowheads were functional-adaptative, or subject to drift processes. The faunal analysis demonstrated that selection was unlikely to be the evolutionary process directly affecting arrowhead morphological traditions in the case study. Diet breadth models were calculated for four Swedish sites that chronologically covered the case study period. The results showed no significant correlation between probable prey-types and point shapes as arrowheads changed shape, and hafting tradition, whilst large ungulates clearly remained central to the economic requirements of the phases, through time.

A population model for the region was then constructed using a modified version of the time averaging method used by Gkiasta et al. (2003). This was similar to the method employed by Gamble et al. (2004, fig. 1) for reconstructing a graphical proxy for Late-glacial population history. The modal value of all available radiocarbon probability distributions from each assemblage in the south Scandinavia case-study, from the Final Maglemose to the Final Ertebølle, were calculated and plotted using the OxCal calibration package. The results were cross referenced with the more detailed 'Harris matrix' temporal model constructed in chapter four to time-step the point assemblages. A close correlation was found between changes in lithic reduction strategies, i.e., from a complex indirect punched blade technique to a less complex direct percussion blade technology (Knarrström 2001), hafting traditions that changed from transverse, to oblique, and back to transverse (Knarrström and Karsten 2003), and the inferred reduction in population levels. A combination of drift and social learning processes are invoked to explain these changes, through the random loss of effective populations of interacting teachers and students, involved in the transmission of more complex technological traditions (Henrich 2004). The causal reasons for the population fluctuations were then examined.

A simple model of land reduction versus changing mammal numbers for the Mesolithic case-study region demonstrated that there would be little adverse effect on contemporaneous faunal and human populations, even if the humans were at a relatively high population density. Qualitative analysis of pollen statistical evidence also showed faunal and human populations were unlikely to have been affected by general changes to ecological patches, as there was no evidence of significant deforestation in the period of the case-study.

Isotope evidence was then used as a climate proxy. Periods of climatic degradation broadly correlated with the drop in populations modeled for the case study. Technological changes to bow-arrow technology in this instance were causally linked to fluctuating climatic conditions in the case study. Changes to lithic technology were therefore explained in terms of loss of technological knowledge due to a drift process, as contemporaneous populations were not totally wiped out or replaced; whilst complex blade technology for the arrowhead was largely lost, as the number of interacting social learners was reduced in times of environmental stress.

7.2 Avenues for future research

A number of key areas, beyond the current scope of this project, could benefit from future research. These are now discussed on a chapter by chapter basis.

In terms of chapter ones analysis of evolutionary approaches to technology, the theoretical emphasis given to social learning mechanisms, as opposed to selection mechanisms, can be productively applied to many areas other than lithic projectile technology. For instance, other lineages of lithic technology such as hand axe technology may be best explained in terms of cultural transmission (Shennan 2001). It seems reasonable to suggest that social learning models can by applied to various technological traditions, using archaeological data from both prehistoric and historic contexts, on a range of materials and common artifact classes, such as pottery, or metallurgy. Historical evidence is highly useful in reconstructing past environments, and can indicate times of resource stress and conflict horizons (Shennan 2003). A comparison of parallel lineages of technologies within a single population may prove particularly enlightening; in terms of possible maladaptive traditions being maintained due to cultural transmission biases (see Henrich 2004). The current dearth of data-rich case studies that utilize social learning theory is a serious problem that needs to be addressed. Also missing from the archaeological literature are detailed experimental studies that determine which technologies are easier to manufacture than others, and which are more difficult to transmit, in terms of different social learning models, and different technological pathways. In theory, the amount of research already gone into examining different lithic technological reduction sequences, and various technological operating chains, is a very good staring point (see Nassaney and Pyle 1999). In the case of lithic projectile technology, even though authors such as Hughes (1998) and Friss-Hansen (1990) have already determined which projectile-systems, projectile points, or arrowheads, may have been generally more functionally efficient on engineering grounds, it is clear from the results of this thesis, that functional efficiency may not be as important as the case-specific cultural transmission mechanism itself. Anecdotal and ethnographic evidence needs to be reinforced by rigorous experimental studies that measure cost-benefits in terms of time required to learn a given technology. The different lineages of bow-arrow technologies presented in chapter two would benefit from comparative experimental work, in terms of establishing the relative costs of manufacturing, learning, and using different technological traditions. For instance, there is already a large amount of specialized literature available concerning the manufacture of various bow-arrow technologies that may prove a good place to start (see Klopsteg 1947; Hardy 1976).

In terms of the chronological work presented in chapter four, it is hoped that the benefits of Bayesian modeling may ensure that this type of analysis becomes commonplace in the archaeological literature of the near future. Even though the OxCal calibration program was originally designed to model the radiocarbon results from single sites into an event order, or to combine multiple samples from single artifacts to give a more probable date to a specific event, the inter-site temporal framework developed here, is potentially very useful in many other archaeological contexts. Various archaeological problems that currently depend on a relatively derived temporal ordering can now be independently questioned using this methodology. In addition, the chronological method developed here may be particularly desirable for the study of periods where the currently available calibration curve is even more variable. For instance, in most of the chronological period prior to the case-study, the calibration curve has a much courser resolution, so the resultant probability distributions for radiocarbon events can be far greater than those presented here. These Bayesian models can be easily improved by the addition of new data. It follows that new radiocarbon results from new phases may give more secure phase start-end boundaries and phase duration probability distributions, than the current model presented in chapter four. As more prior archaeological information is published in conjunction with details of radiometric samples, following the example of the detailed Swedish excavation reports used in this project, greater temporal resolution can be achieved in the future. Similarly, as new calibration curves become available, the model in chapter four can be re-rerun and refined.

In terms of chapter five's statistical study of the points, weight and thickness variables for the Blak II points could, when available, be added to the analysis, which may give a clearer quantitative indication of inter- and intra-site time averaged morphological variation. It follows that more assemblages could be added to the analyses, as they become available. A clearer representation of the development of the earlier lithic assemblages could be achieved, by separating out the earliest phase of the Tågerup Kongemose phase arrowheads, which have been identified as transversely hafted (Karsten and Knarrström 2003), and clearly correspond to the rhombic shape of the Blak points. However, there is currently no obvious way to separate out a large enough independently ^{14}C dated sample of the earlier transversely hafted Tågerup points, from the later obliquely hafted Tågerup Kongemose (phase one) points. The earlier transversely hafted points are currently dated by their generally closer position to the ancient shoreline, and relatively by Vang Petersen's (1984) typological method. Although rhomboid points are generally found in the same stratum as the obliquely hafted points, and are generally nearer to the earliest part of the settlement, which is towards the ancient shoreline (Karsten and Knarrström 2001), the radiometric dates and osteological data are all obtained from organic samples which, although taken from the same general phase as numbered, cannot currently be subdivided into a more precise spatial distribution than already presented. To avoid any circularity of argument, Vang Petersen's specific typological method was not used here to temporally date the Tågerup assemblages, to ensure a consistent comparison of all the points, from all the sites, in terms of all the available radiometric data. A finer-grained spatial comparison of intra- and inter-site point shape distribution is beyond the scope of this thesis however as the Scandinavian arrowheads can be located to their respective square-metres, this could prove a very interesting project.

In chapter six, the faunal remains from the remaining five phases currently not included in the prey-species and diet breadth models, could be easily added at a later date, once their osteological analysis is completed and published. However, it is hoped that the osteological analysis presented is sufficient for the purpose of this thesis - as it seems clear that selection is effectively eliminated as the causal mechanism for changes to the case-study point morphology.

It is hoped that the methodology and data presented in this thesis will form the basis of a wider research project that could help explain the technological changes in south Scandinavia, and elsewhere, at different chronological phases of prehistory. The comparatively late adoption of Neolithic (TRB) cultural traits in the case-study region (Price 1991), may, or may not be explained in terms of successful localized (marine) resource adaptations eventually failing due to environmental and population stress. The large amount of extant published radiometric data available throughout the case-study area and period would make this a cost-effective and highly informative project. The role of conflict in relation to changing populations could be addressed in terms of the influence of intrusive Neolithic populations and technologies. Complex barbed-and-tanged arrowheads could be analyzed in terms of existing paradigms of geo-temporal directions of technological transmission, which could in turn be challenged by hypotheses generated by cladistics following O'Brien's methodology as later bifacial technologies have enough potential character states for a cladistic analysis (O'Brien et al. 2001; see chapter three). Hypothesized population fluctuations may coincide with increased rates of violent cause of death, as identified in contemporaneous human remains. This evidence could be directly related to either fluctuating resources, and/or a cultural transmission mechanism such as a prestige-bias (Boyd and Richerson 1985) key to a specifically identifiable age group, presumably young men (Wrangham and Petersen 1996) where enculturated competition for honour and resources may be directly linked to inclusive fitness, as seems to be the case elsewhere (see Maschner and Maschner 1998; Ames and Maschner 1999).

As alluded to in chapter six, a particularly challenging line of research would be to apply the findings of Clutton-Brock's (2002) long-term environmental study on the island of Rhum in the Inner Hebrides which related climatic variation directly to fluctuating deer and sheep populations, to the archaeological record of south Scandinavia. This is clearly a complex undertaking when just one or two species are being analyzed in a modem context, but if assemblages are time-averaged and time-stepped, agent based computer modeling could prove highly productive when analyzing fluctuating prehistoric human and animal populations, for instance in relation to the introduction of new biface technologies. Following Hill and Hurtado's (1996, 187) Life History Theory (LHT), and their work with the Paraguayan Ache peoples, it is clear that hunter-gatherer fertility rates are complex, but not impossible to model. The extent to which fertility rates in less complex societies are particularly vulnerable to climatic fluctuations, which according to Clutton-Brock (2002) is a key factor that clearly affects certain animal (prey) species, is not clear from the current ethnographic literature. However, the positive results from Gamble's climate and population modeling for the Late Glacial indicate that fertility rates may be a key issue (Gamble et al. 2004, fig. 4). It follows that LHT may prove a potentially powerful methodological tool for the archaeologist, in terms of the formal modeling of demographics, and the subsequent technological changes in prehistoric populations. To that end, achieving greater temporal resolution of environmental fluctuations should be a key objective of future research. It seems likely that with better temporal resolution of environmental, population, and technological changes, archaeology is now poised to make a unique contribution to the social sciences.

In conclusion, it is hoped that this thesis has demonstrated that archaeology is too important to leave to those without a cumulative programme of research. This project has been unashamedly ambitious in its methodology and scope; the evolution of bow-arrow technology has proved to be no simple matter. Unlike previous evolutionary works, which promise much but deliver little in the way of supporting evidence (Boone and Smith 1998), a good balance has been achieved between the amount of evolutionary theory, and the quantity of empirical data. To the best of my knowledge, the integration of evolutionary models presented in this work, inspired by developed Darwinian principles, has never been attempted before with such fine-grained archaeological data, and temporal resolution. It is my sincere hope that this study is not the last of its lineage.

Figures, Tables, and Bibliography.

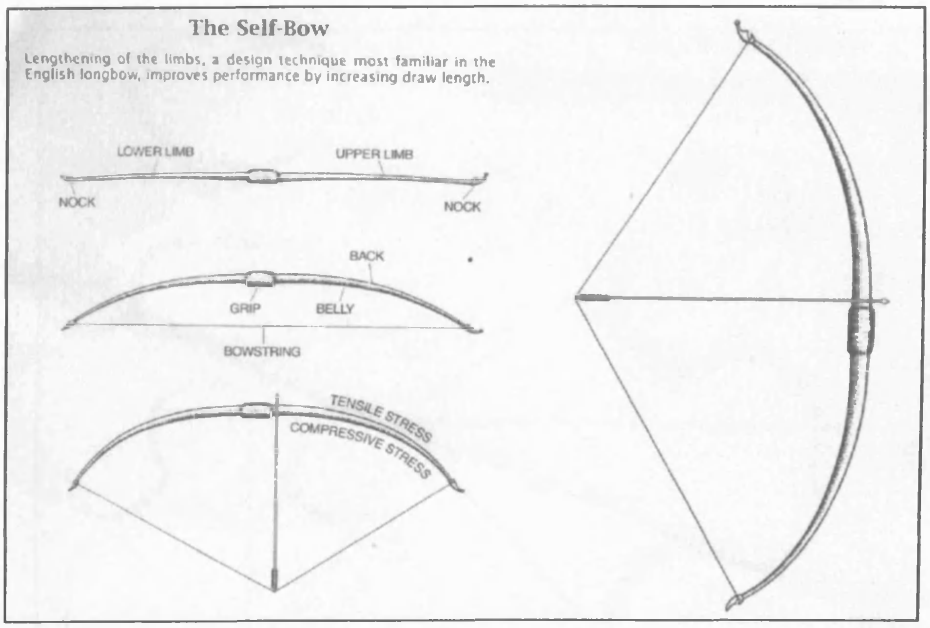


Fig. 2.1 Diagram to illustrate the technical characteristics of the self bow (Bergman and Miller 1997).

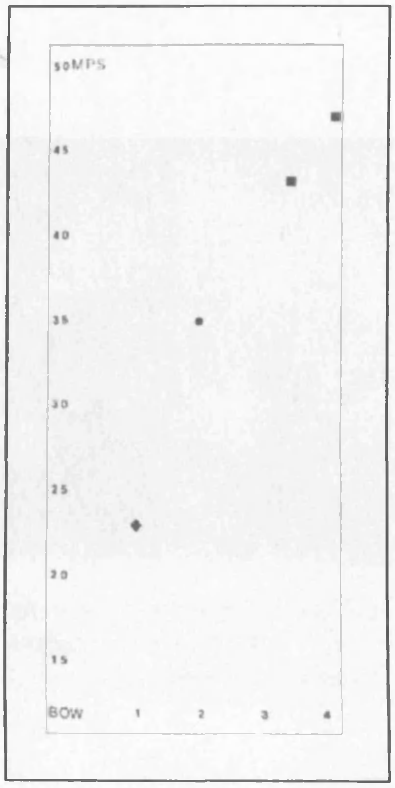


Fig. 2.2 Graph showing characteristically different maximum velocities for different types of bow in maximum metres per second. Bow one is actually a spear-thrower, bow two is an African simple bow, and bows three and four are replicas of Egyptian composite bows (Miller et al. 1986).

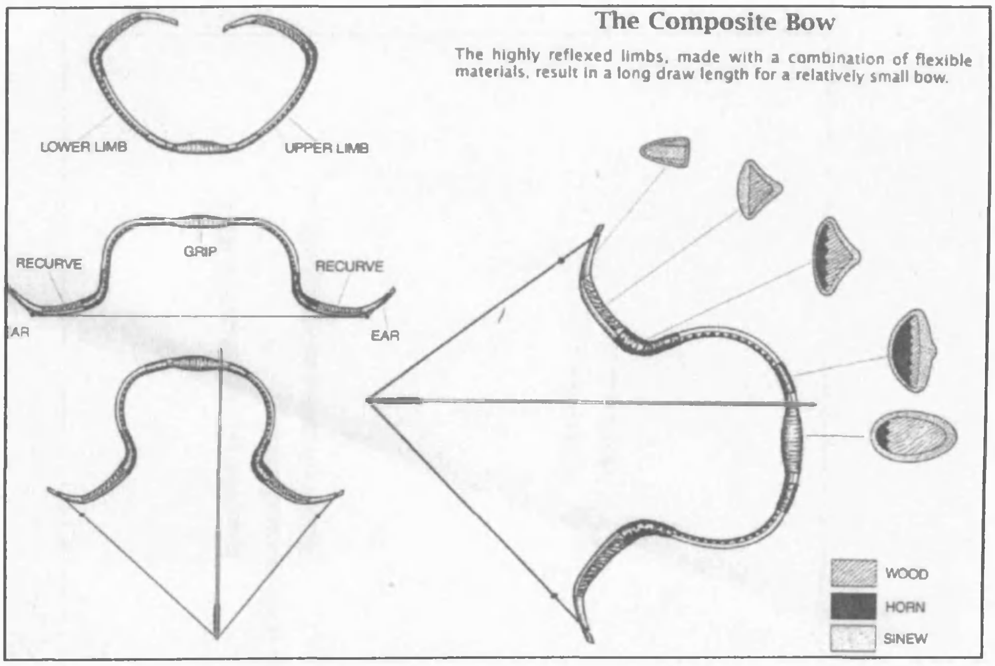


Fig. 2.3 Diagram to illustrate the technical characteristics of the composite bow (Bergman and Miller 1997).

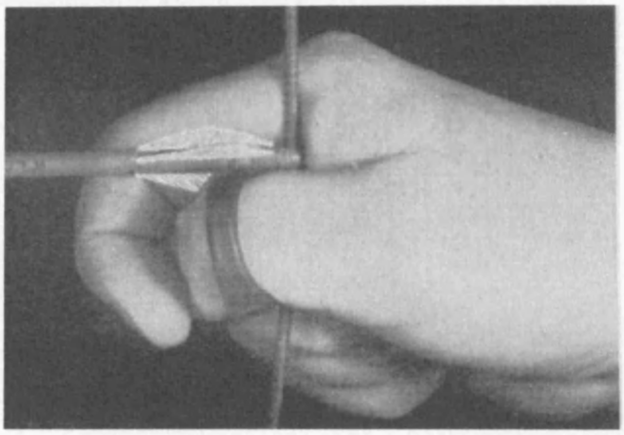


Fig. 2.4 Photograph of the counterintuitive 'thumb-grip release', with protective thumbring, often an essential characteristic of Near Eastern and Far Eastern composite bows that require long, powerful draws (Klopsteg 1947).

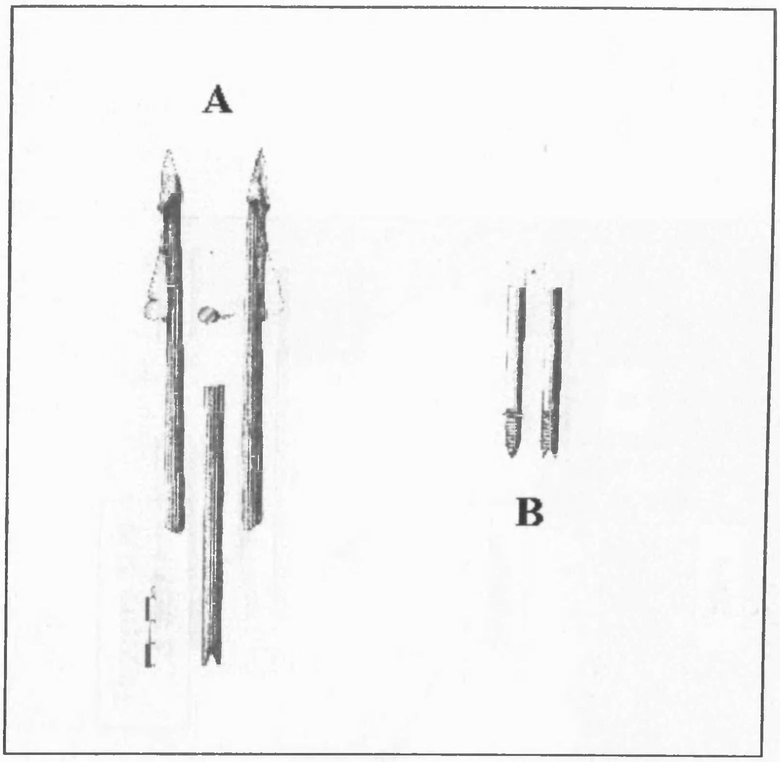


Fig. 2.5 Diagram to show (A) the Swedish Scanian Lilla Loshult arrow, and (B) nock-ends diagnostic of arrows (Rozoy 1988).

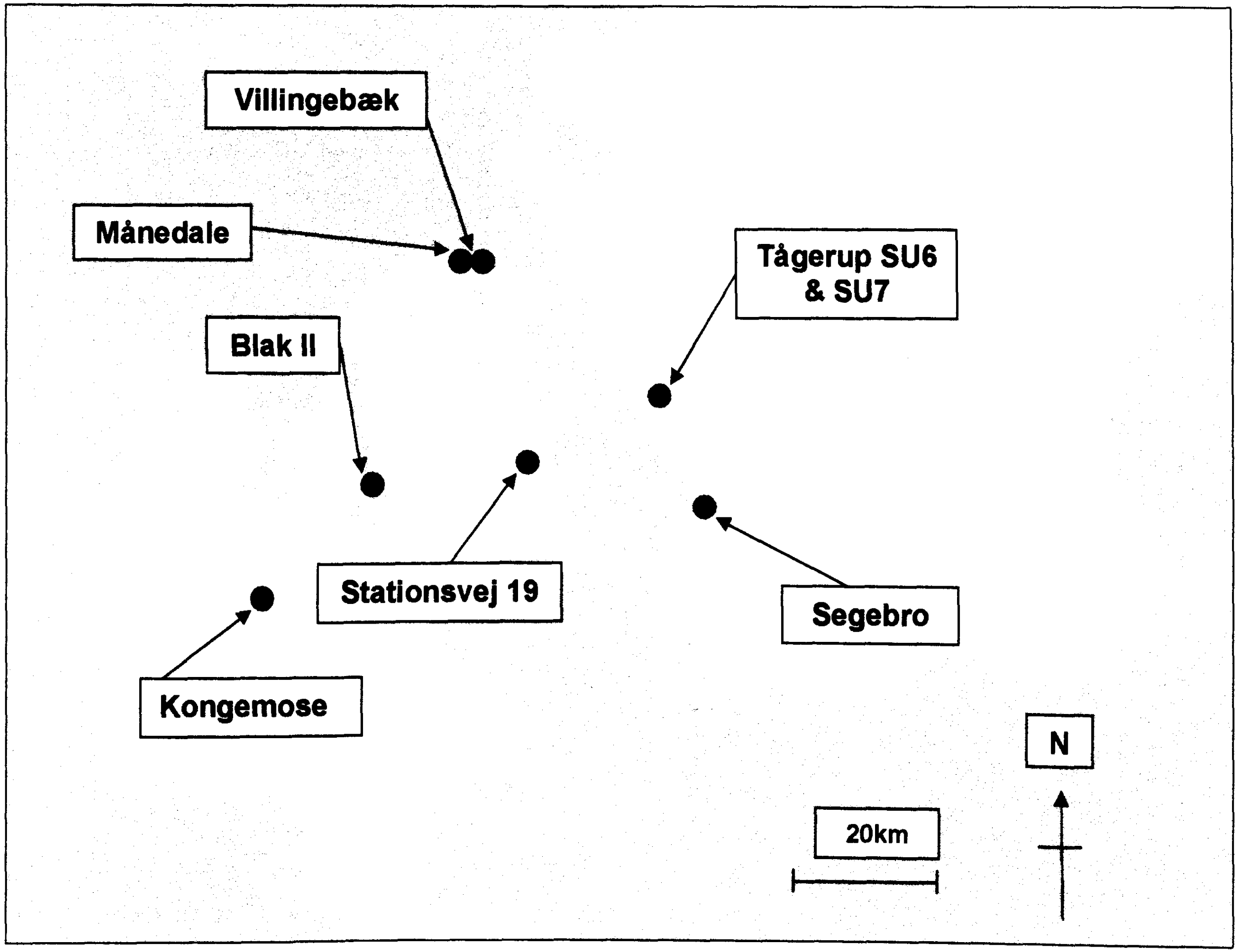


Fig. 3.1 Map of south Scandinavian case-study area.
Note that the Tågerup site has three point-bearing phases; Tågerup Kongemose, Tågerup Ertebølle, and SU7.

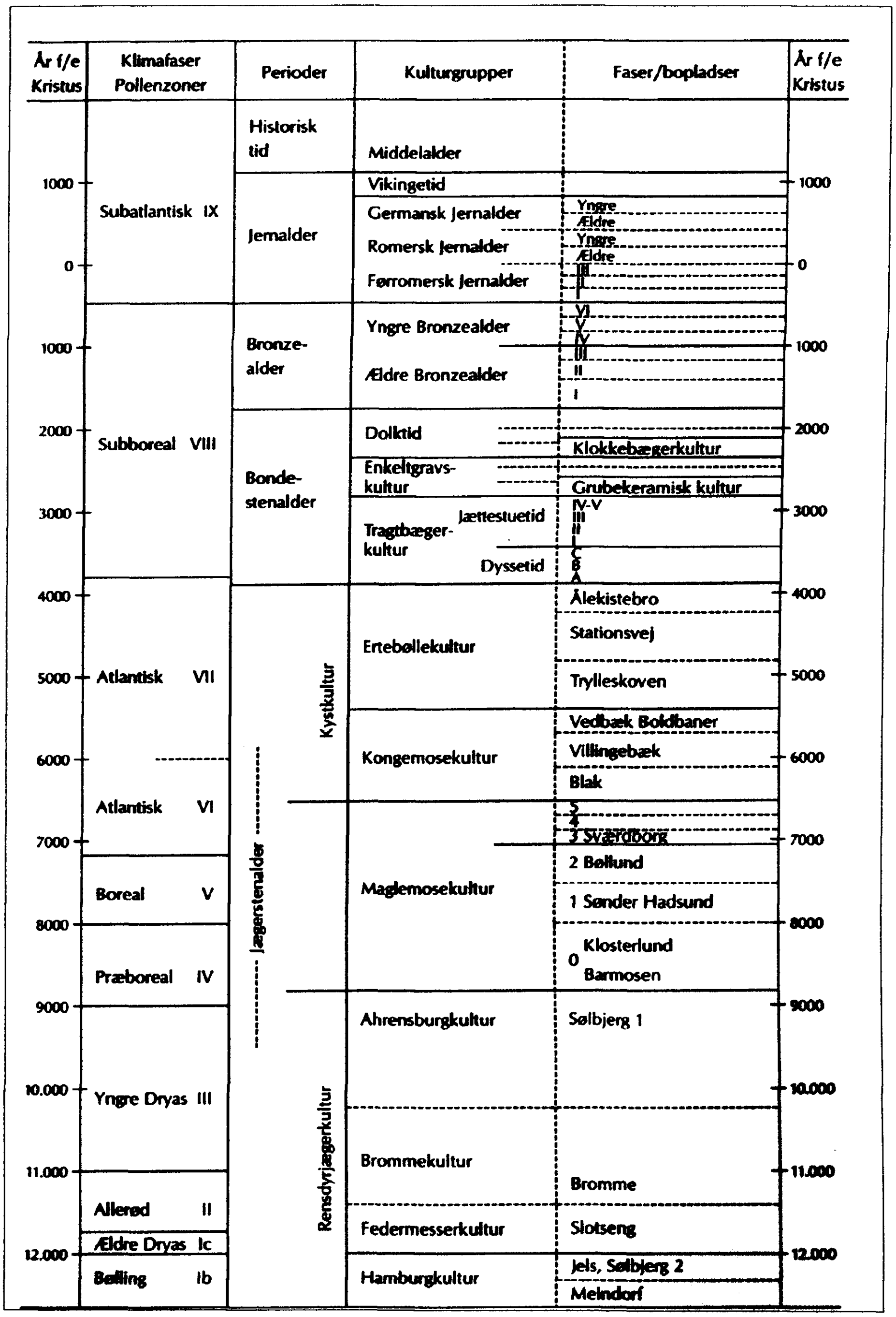


Figure 3.2 Vang Petersen's (1999) southern Scandinavian chronology.

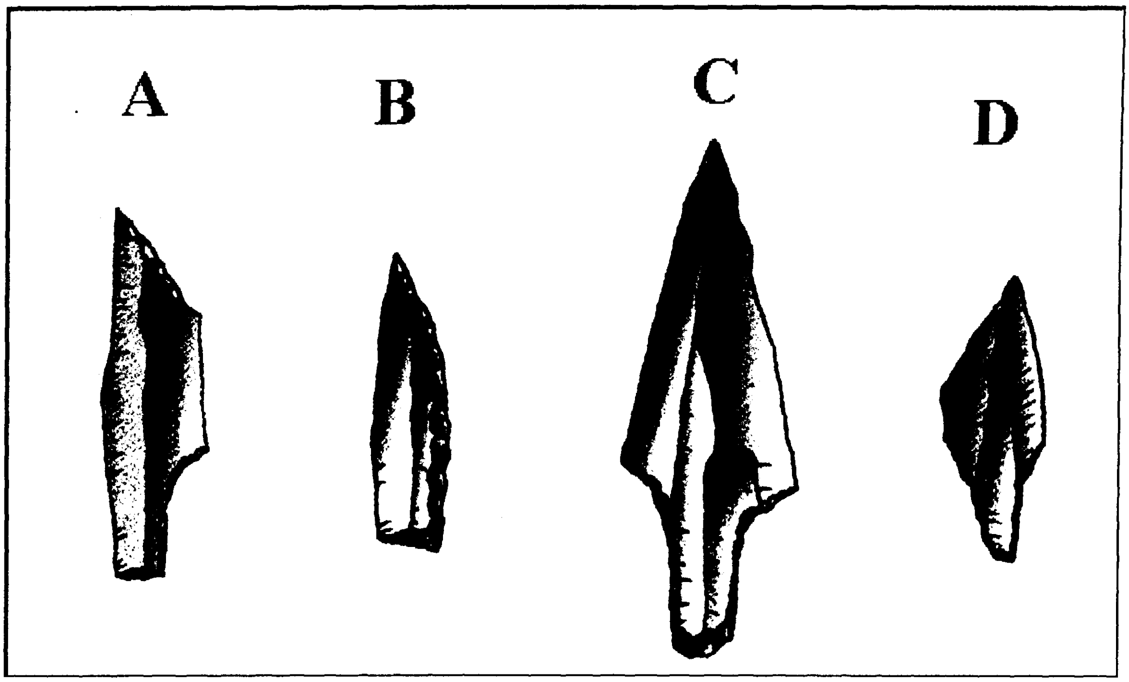


Fig. 3.3 Traditional projectile point cultural divisions (Andersson and Knarrström 1999).

A= Hamburg culture, B = Federmesser culture,
C=Bromme culture, D= Ahrensburg culture.

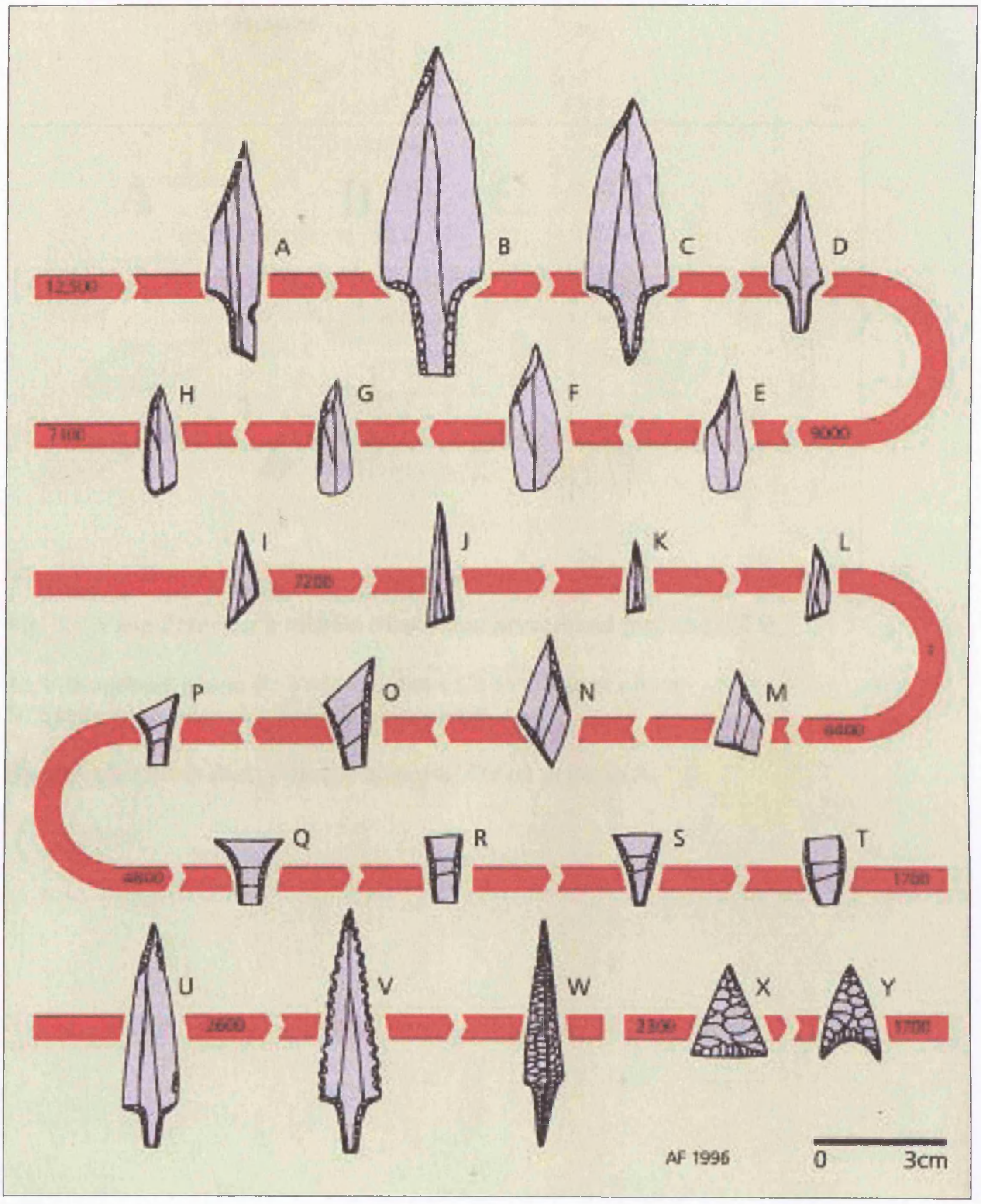


Fig. 3.4 Anders Fischer's linear point sequence (1997).

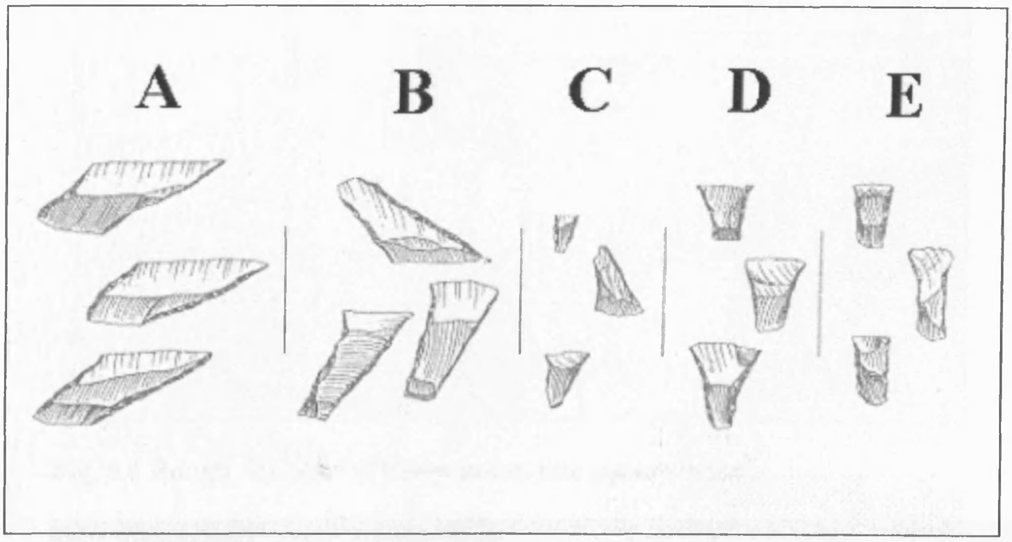


Fig. 3.5 Vang Petersen's Middle Mesolithic arrowhead phases (1984).

A: Villingebæk phase B: Vedbæk phase C: Trylleskov phase D: Stationsvej phase E: Aalekistebro phase.

Sorensen's (1996) Blak phase is now positioned prior to A.

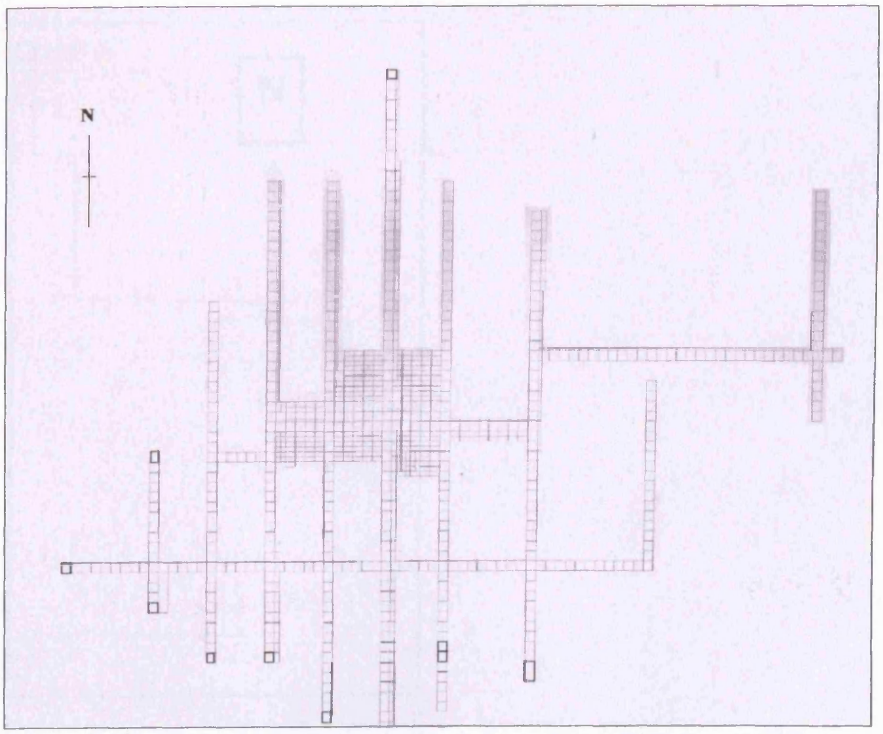
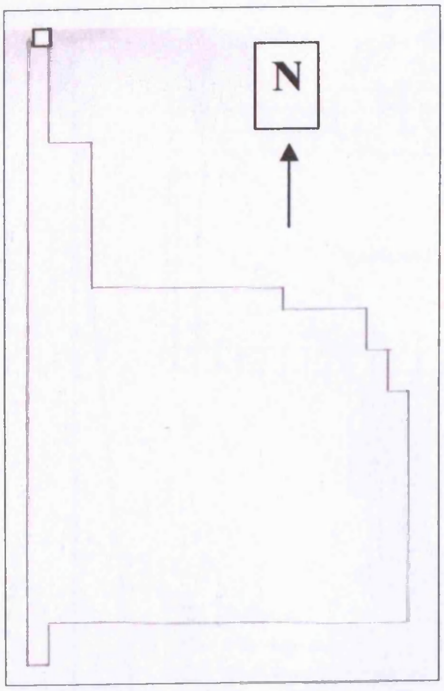


Fig. 3.6 Rough site plan of Kongemose, one square = $1m^2$.

Fig. 3.7 Selection of Kongemose arrowheads.



3.8 Rough site Plan of Villingebæk Øst A from Vang Petersen (1979). 1 square = 1m^2.

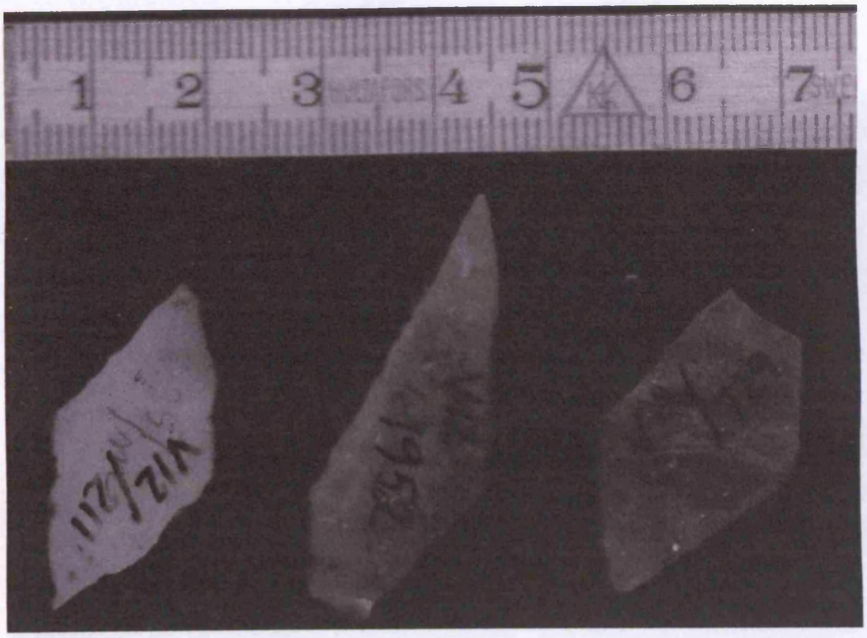


Fig 3.9. Selection of points from Villingebæk Øst A.

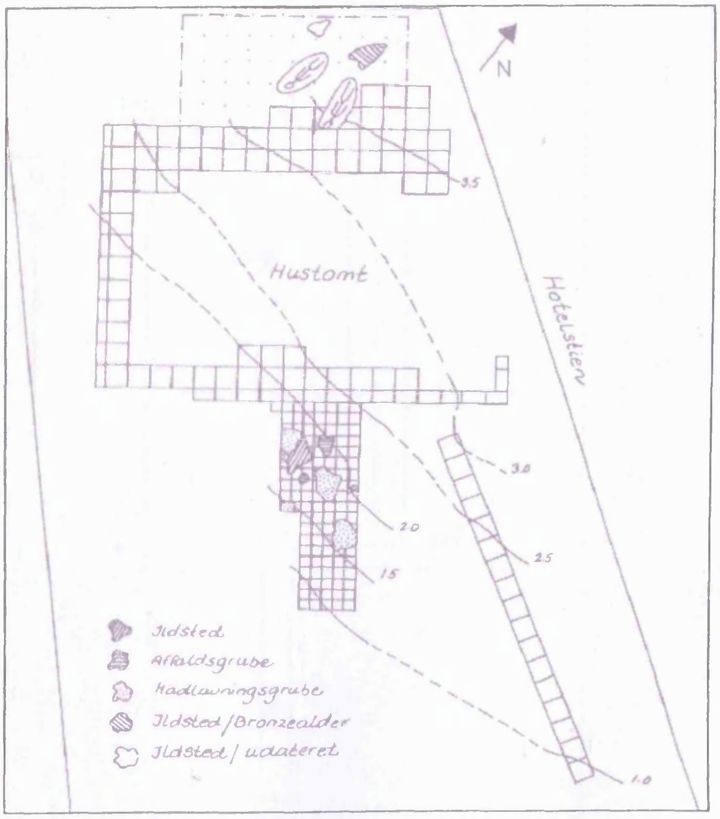
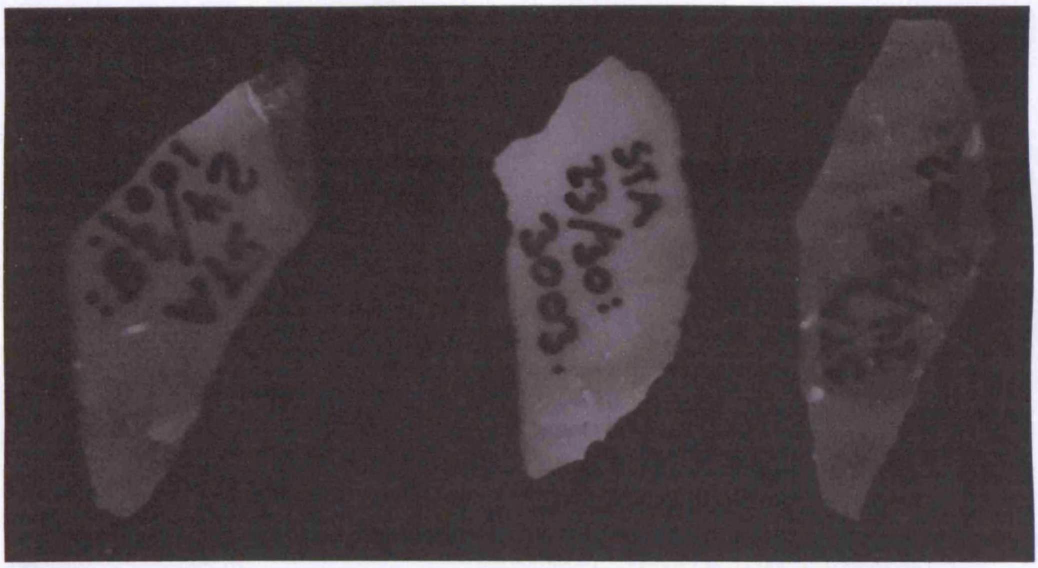


Fig. 3.10 Stationsvej 19 site plan (Bøttiger-Mørk et al. 1997).



3.11 Selection of Stationsvej 19 points. Scale: ca. x2.

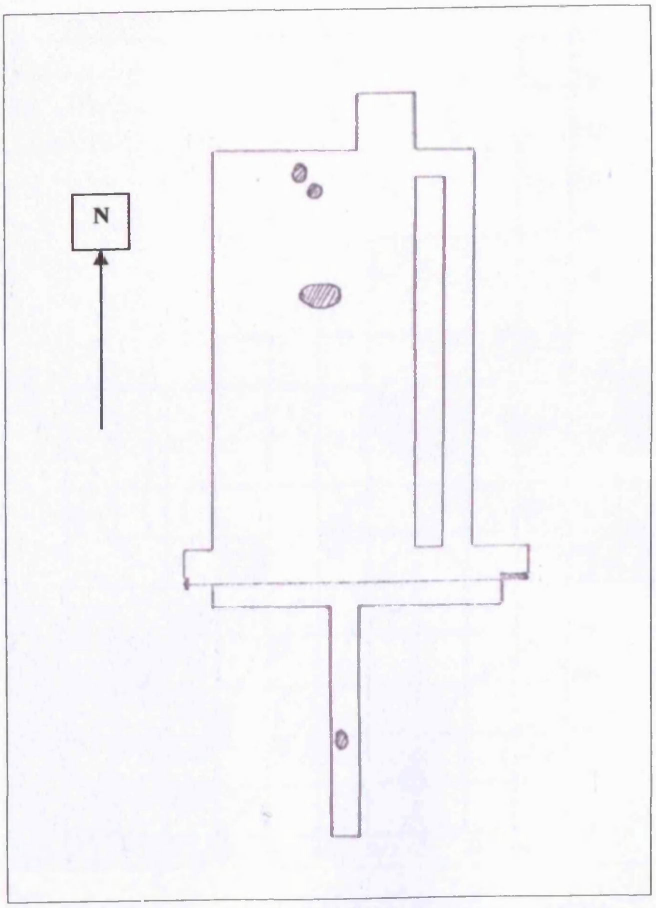


Fig. 3.12 Rough map of Månedale site plan.

Fig. 3.13 Selection of Månedale points. Scale: ca. x2.

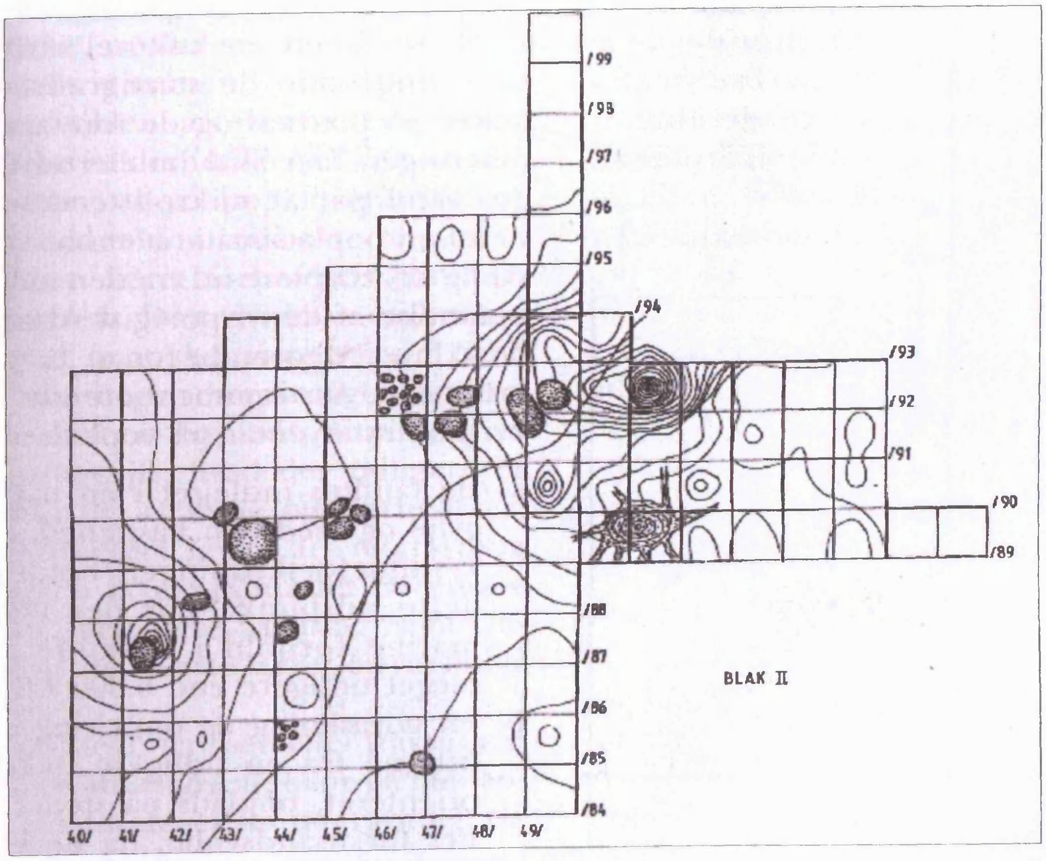


Fig. 3.14 Site plan of Blak II from Sørensen (1996).

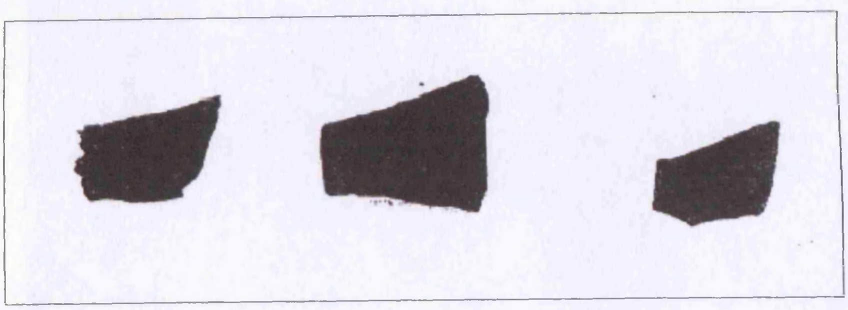


Fig. 3.15 Selection of Blak II points. Scale ca. 1:1.

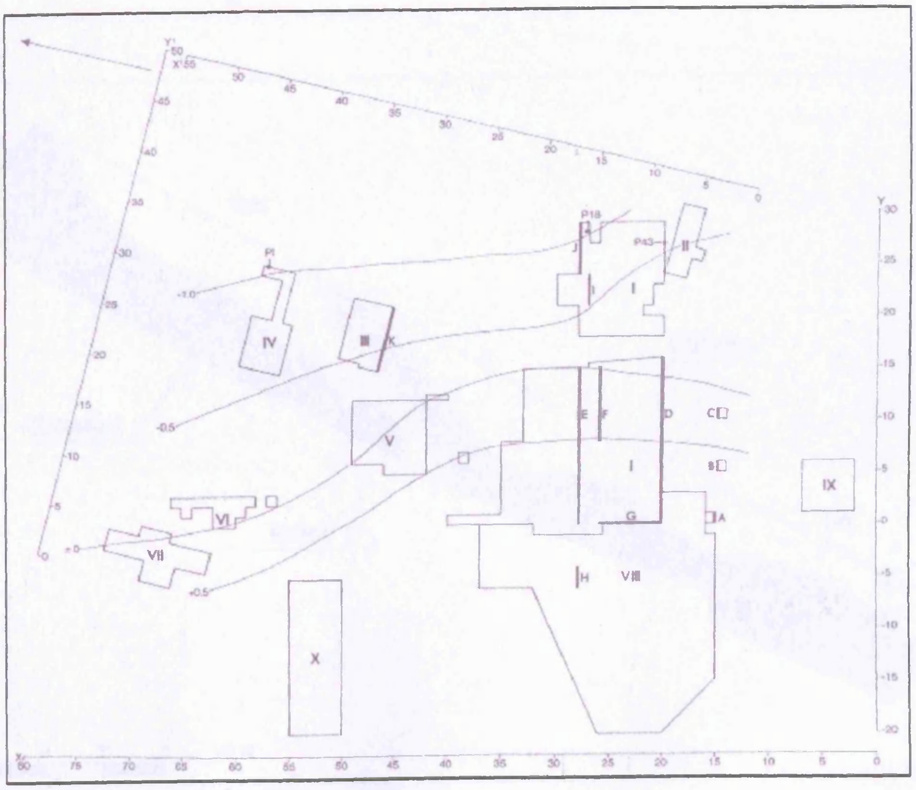
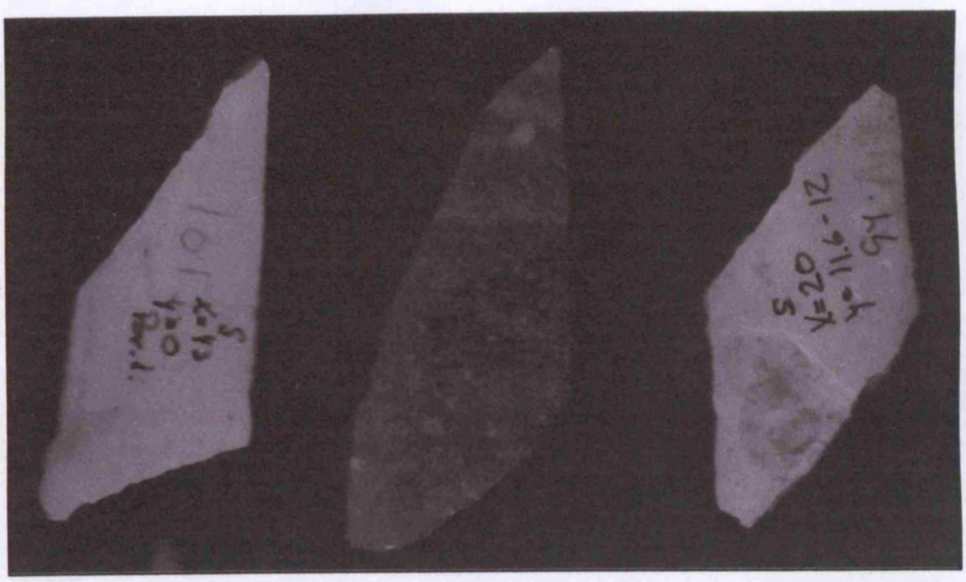


Fig. 3.16 Site plan of Segebro (Larsson 1982).



3.17 Selection of Segebro points. Scale: ca. x2.

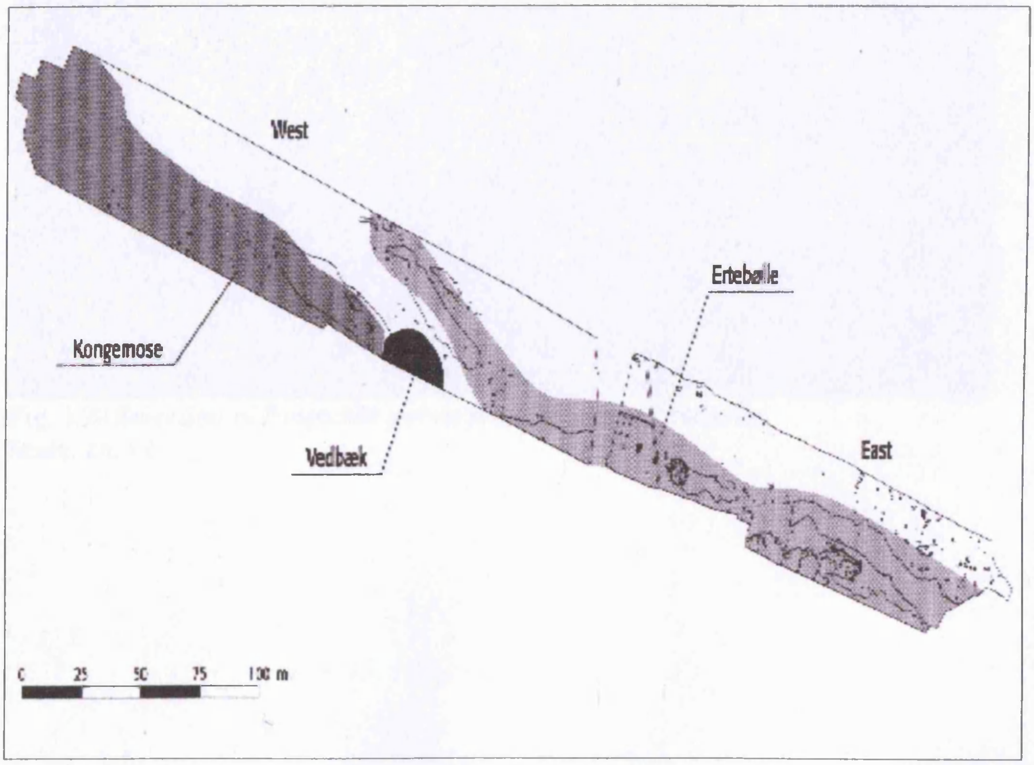


Fig 3.18 Plan of Tågerup Excavation, showing shaded Tågerup and Kongemose phases (Karsten and Knarrström 2003).

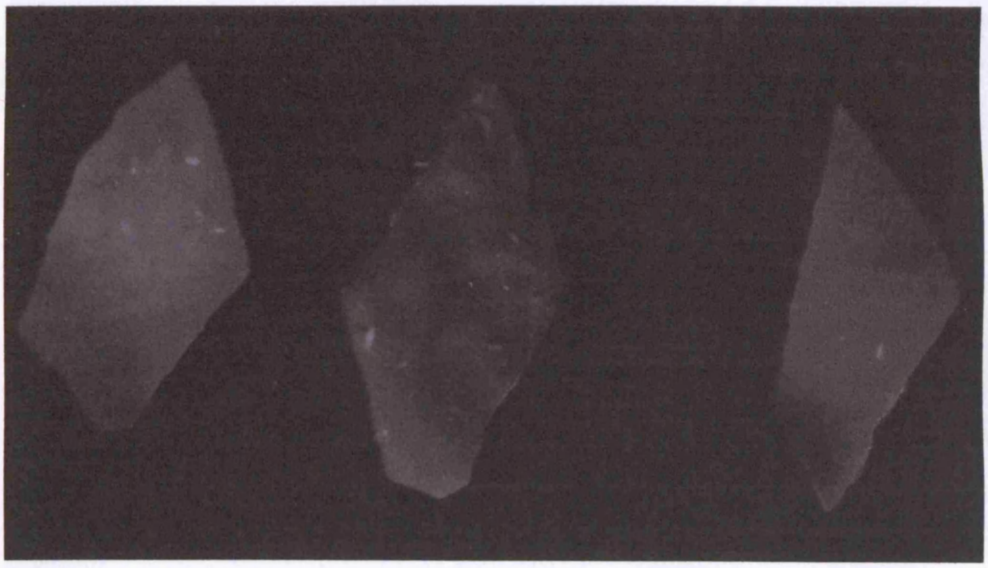


Fig 3.19 Selection of Tågerup Kongemose projectile points. Scale: ca. x2.

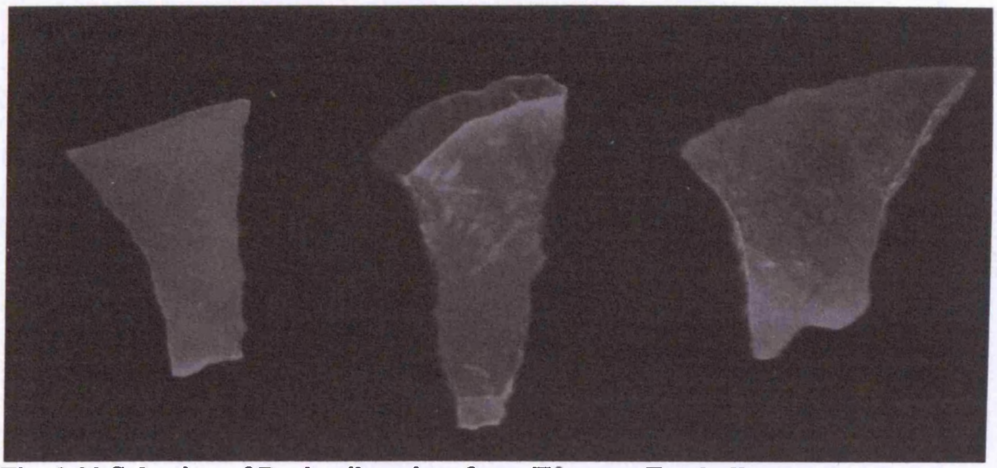


Fig. 3.20 Selection of Projectile points from Tågerup Ertebølle.
Scale: ca. x2.

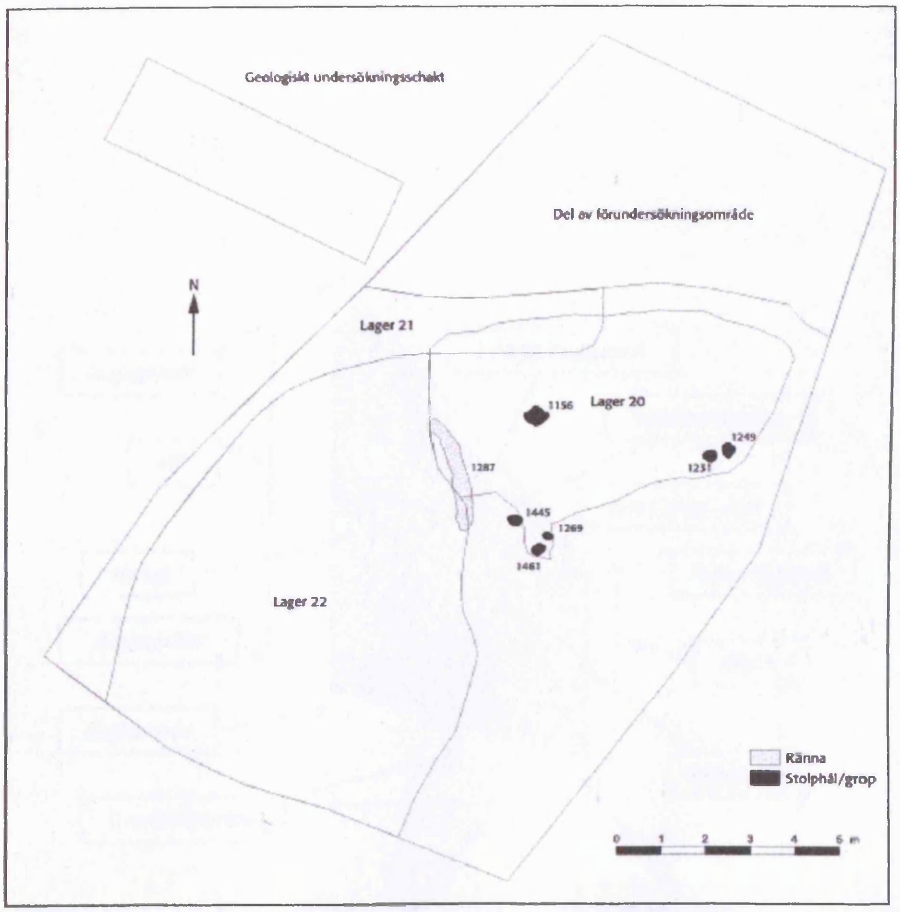


Fig 3.21 Site Plan from Tågerup Intermediate (SU7).

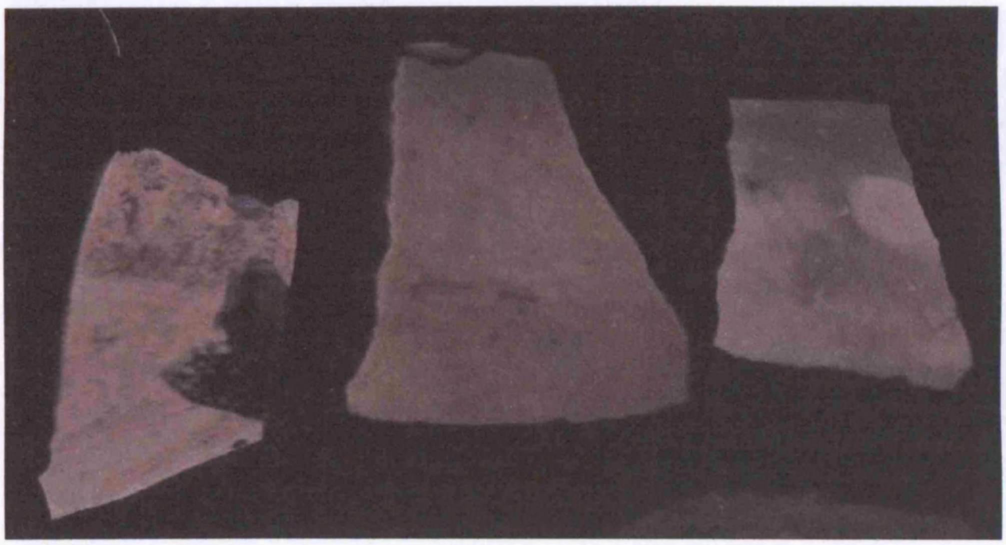


Fig 3.22 Selection of points from Tågerup Intermediate (SU7), Scale: ca. x2.

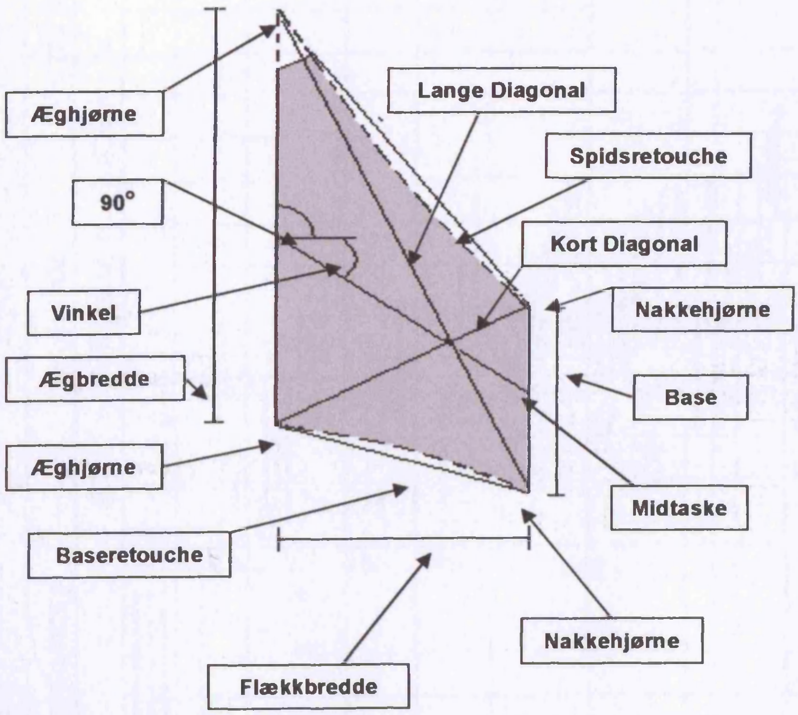


Figure 4.1 Schematic of Vang Petersen's (1979) point dimensions and terminology.

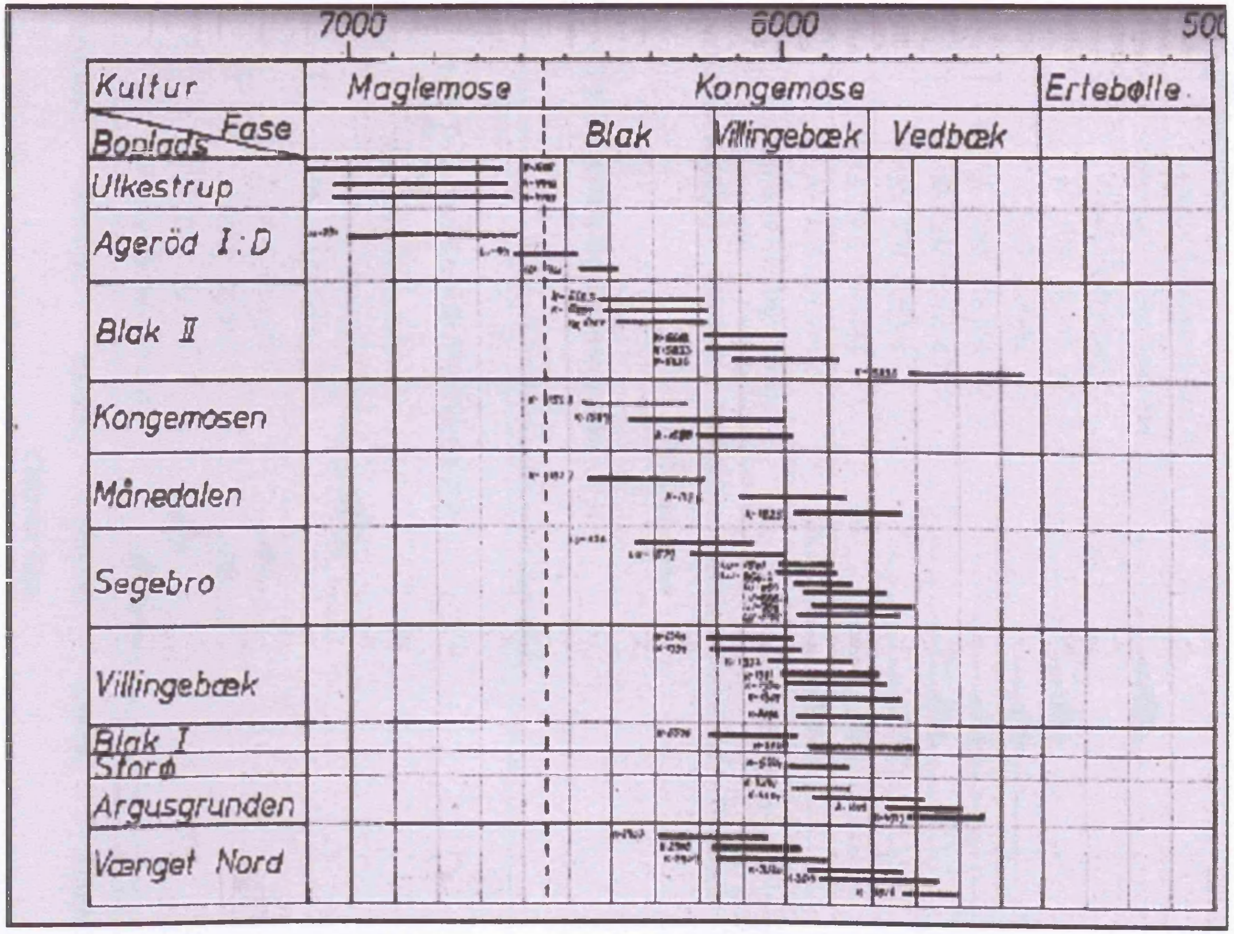


Fig. 4.2 Sørensen's (1996) ^{14}C box plot.

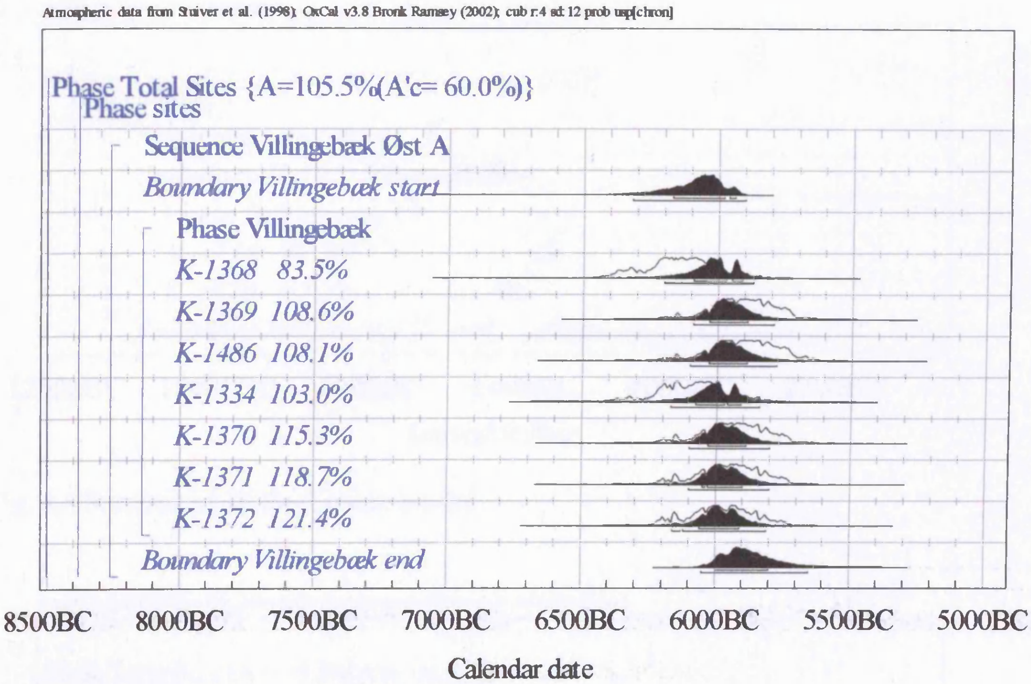


Fig. 4.3 Villingebæk final phase model.

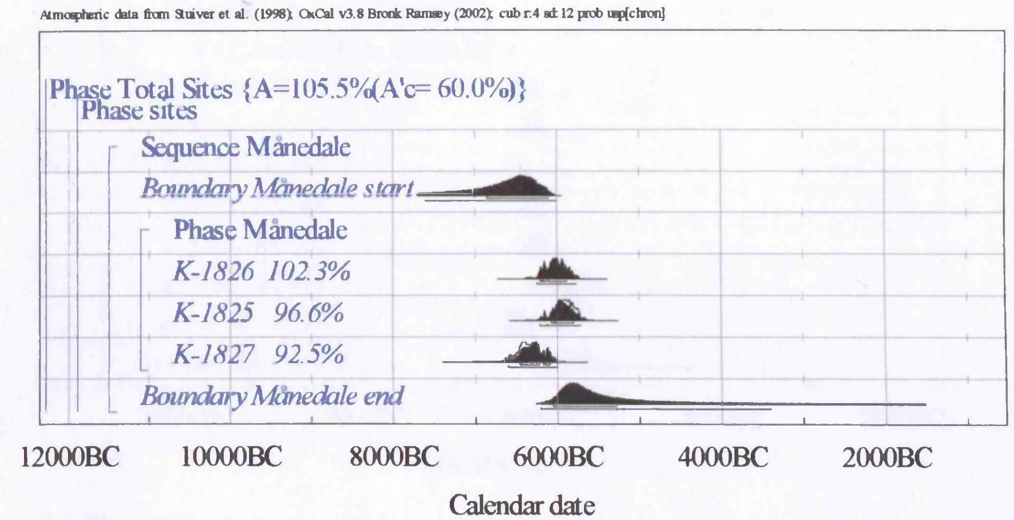


Fig. 4.4 Månedale final phase model.

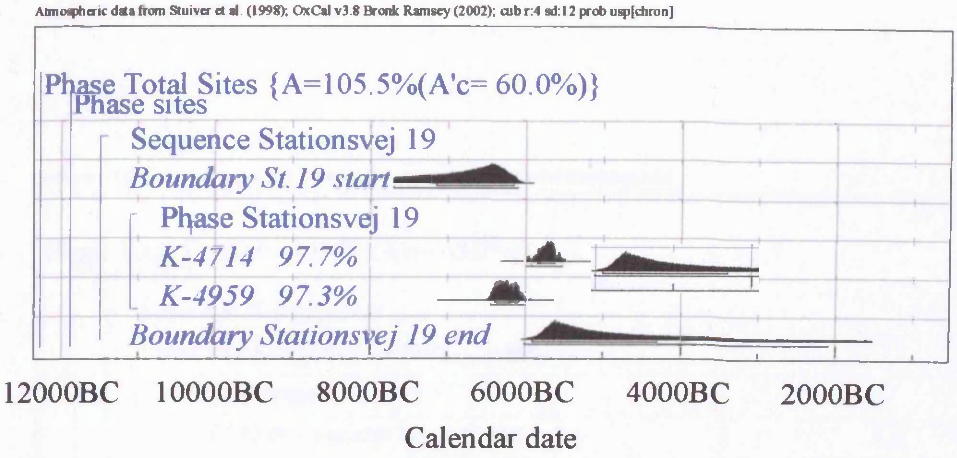


Fig. 4.5 Stationsvej 19 final phase model.

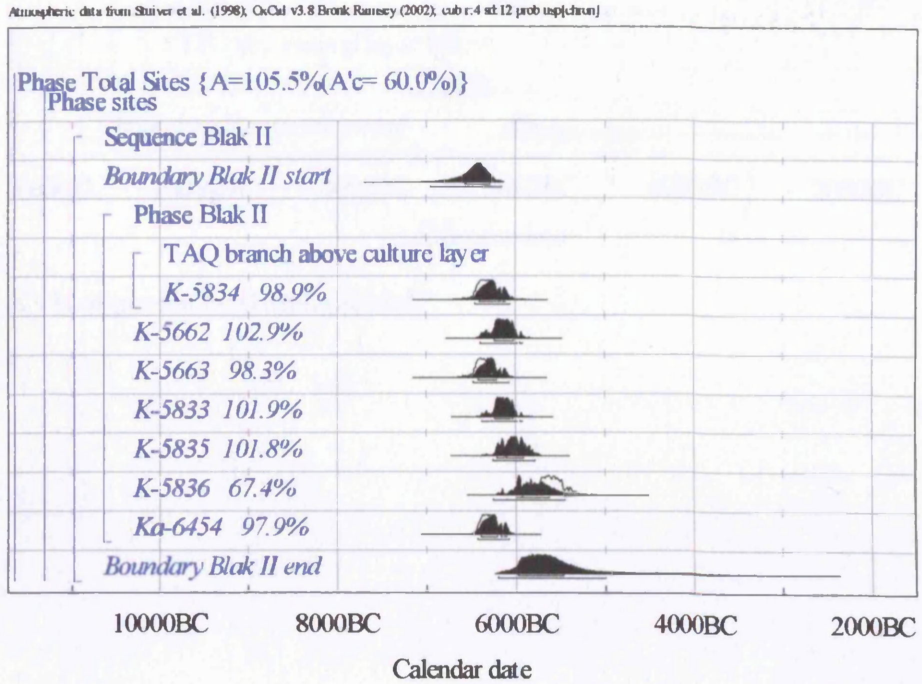


Fig. 4.6 Blak II final phase model.

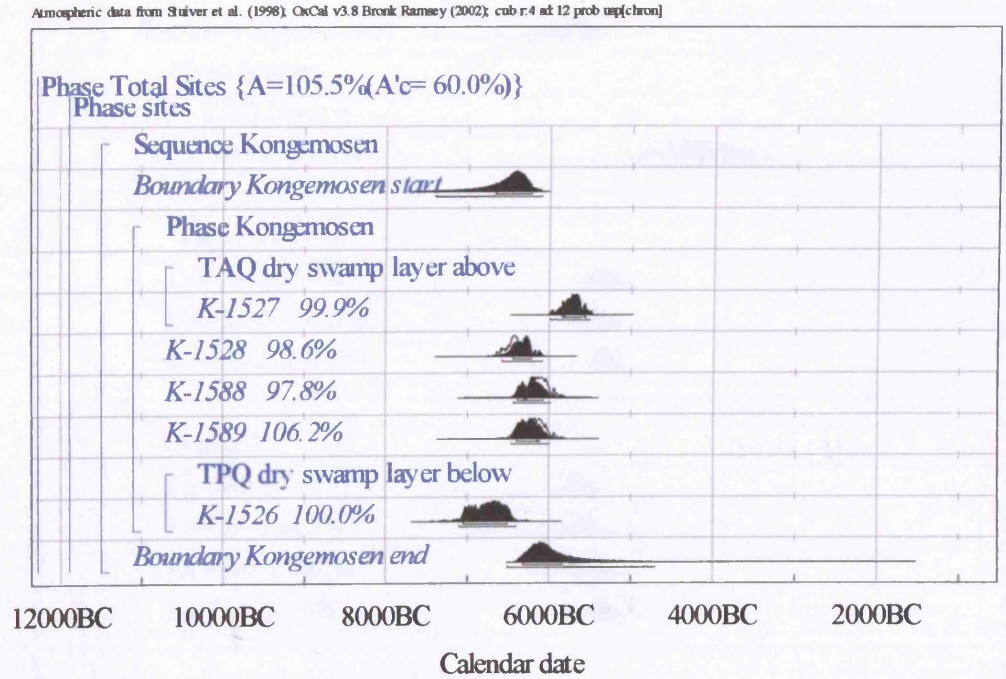


Fig. 4.7 Kongemose final phase model.

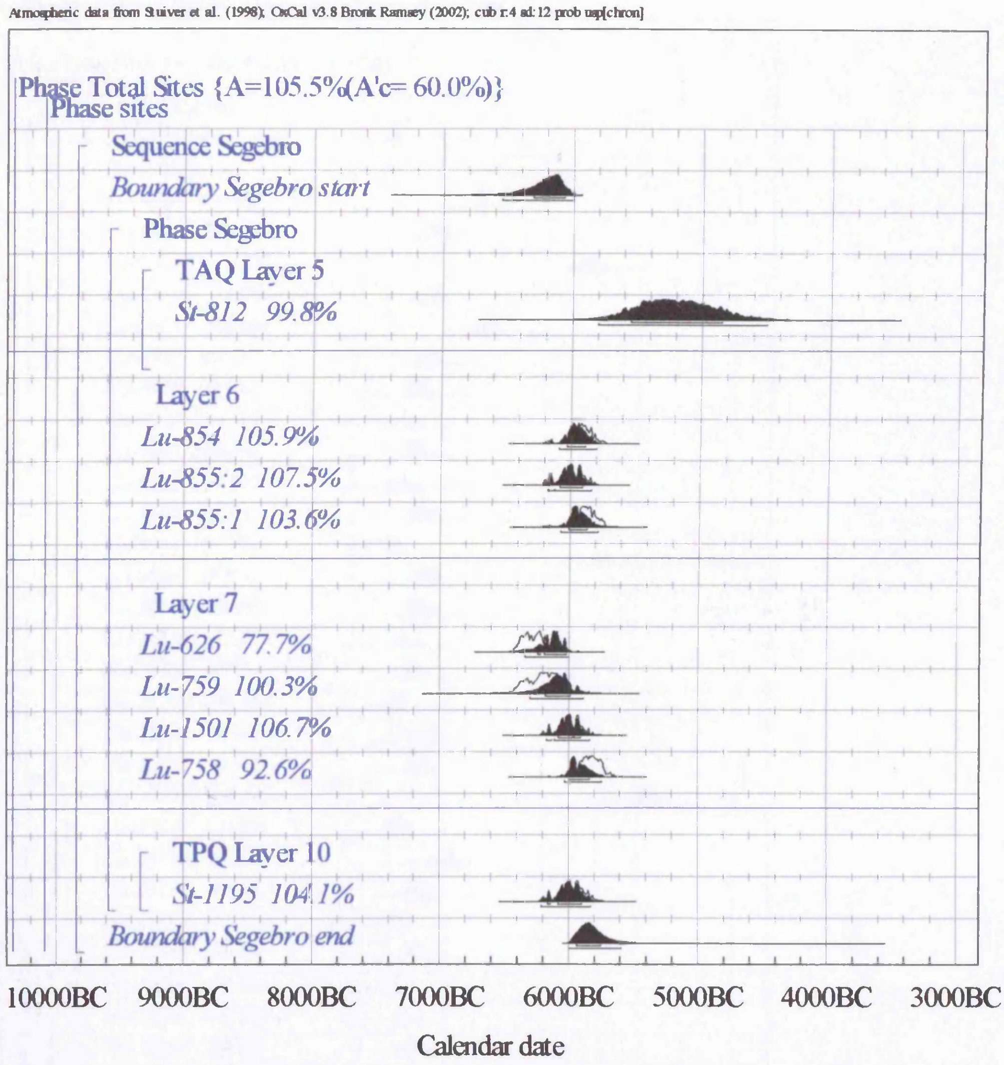


Fig. 4.8 Segebro final phase model.

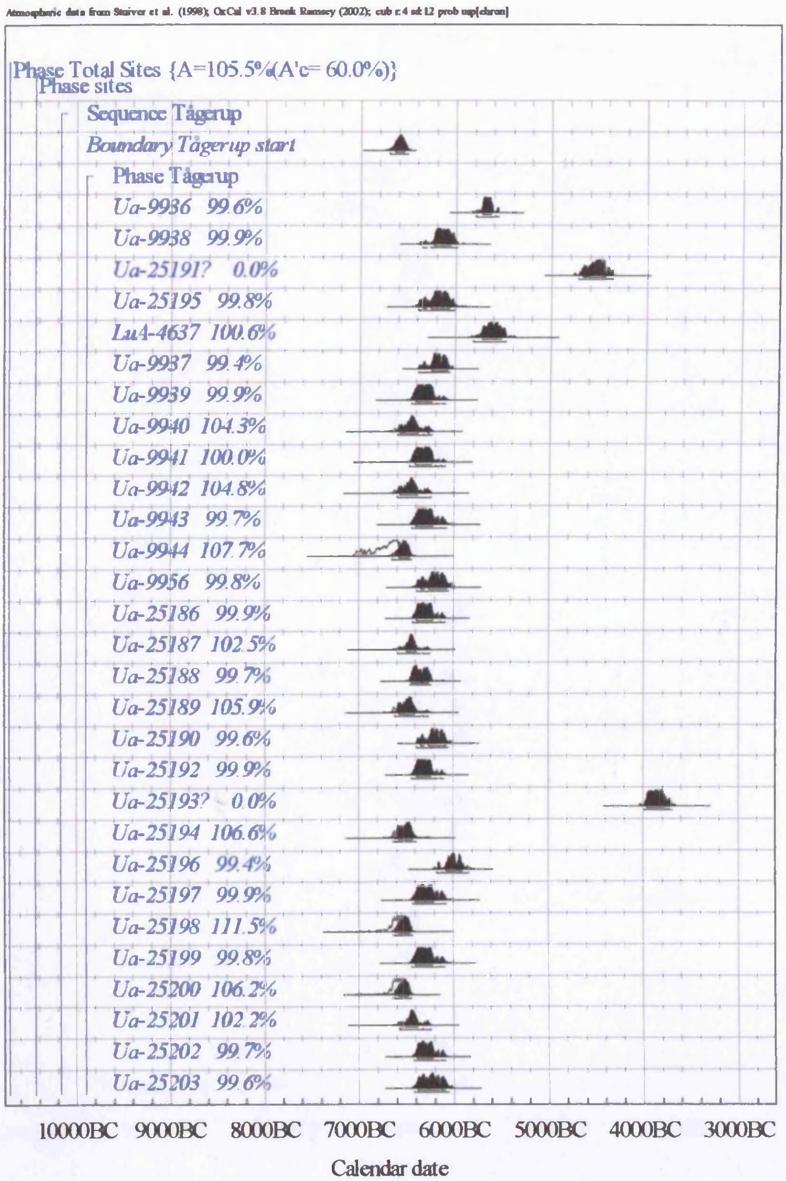


Fig. 4.9.A Tågerup Kongemose final phase model.

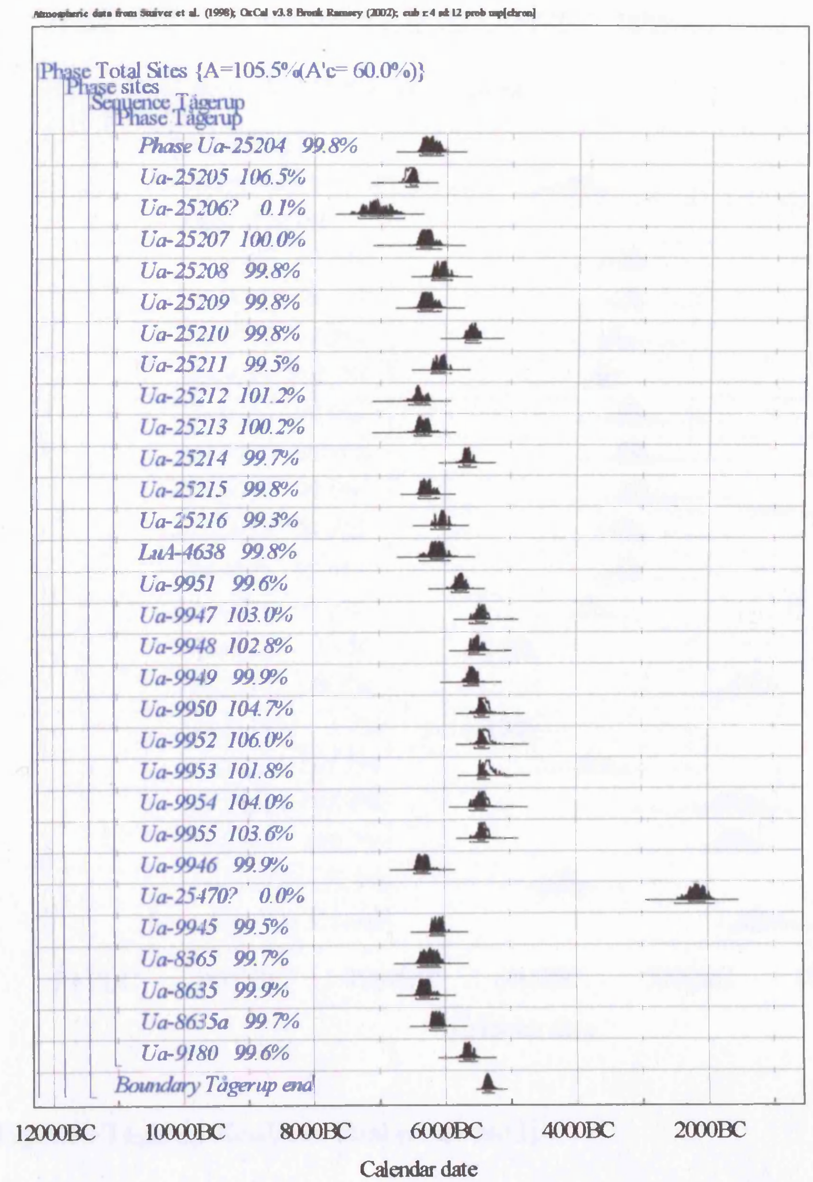


Fig. 4.9.B Tågerup Kongemose final phase model.

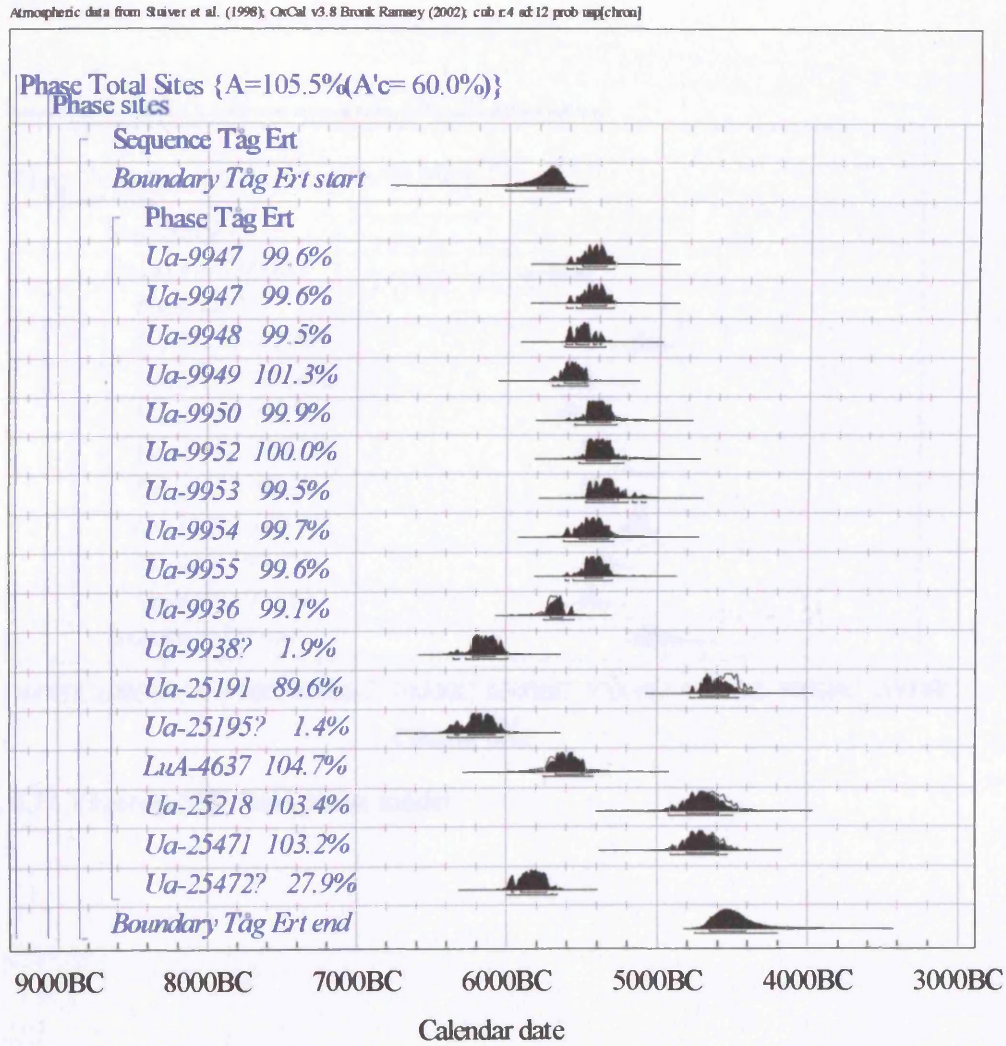


Fig. 4.10 Tågerup Ertebølle final phase model.

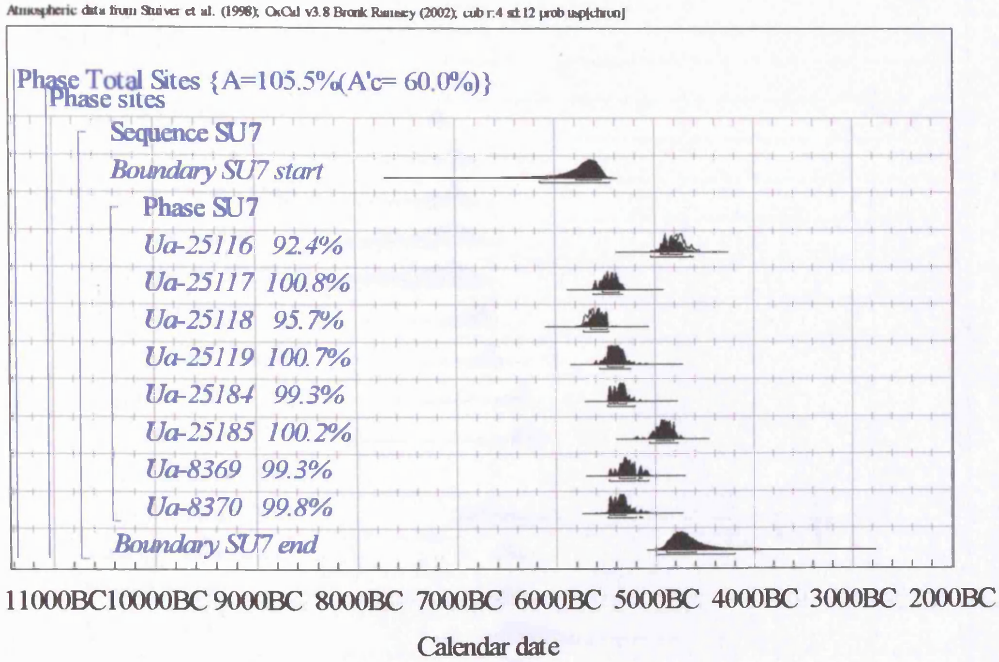


Fig. 4.11 Tågerup SU7 final phase model.

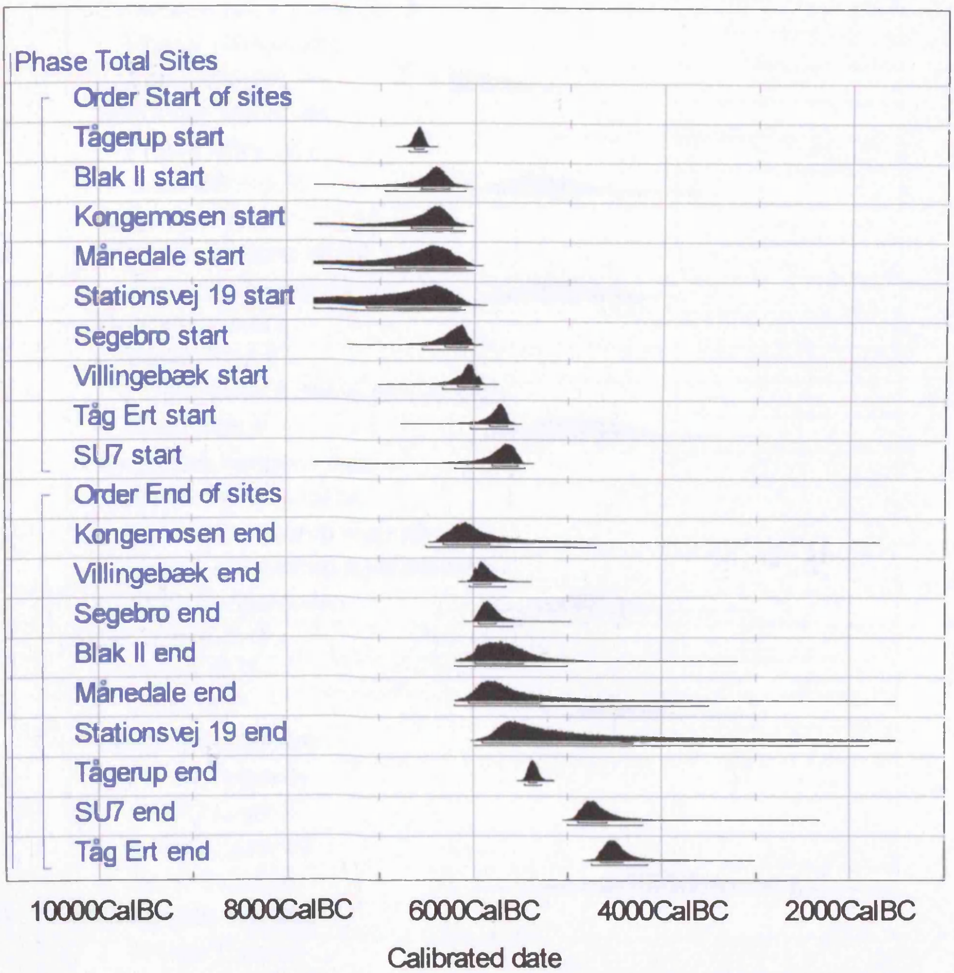


Fig. 4.12 Case-study chronological model Start and End distributions in calibrated calendar years.

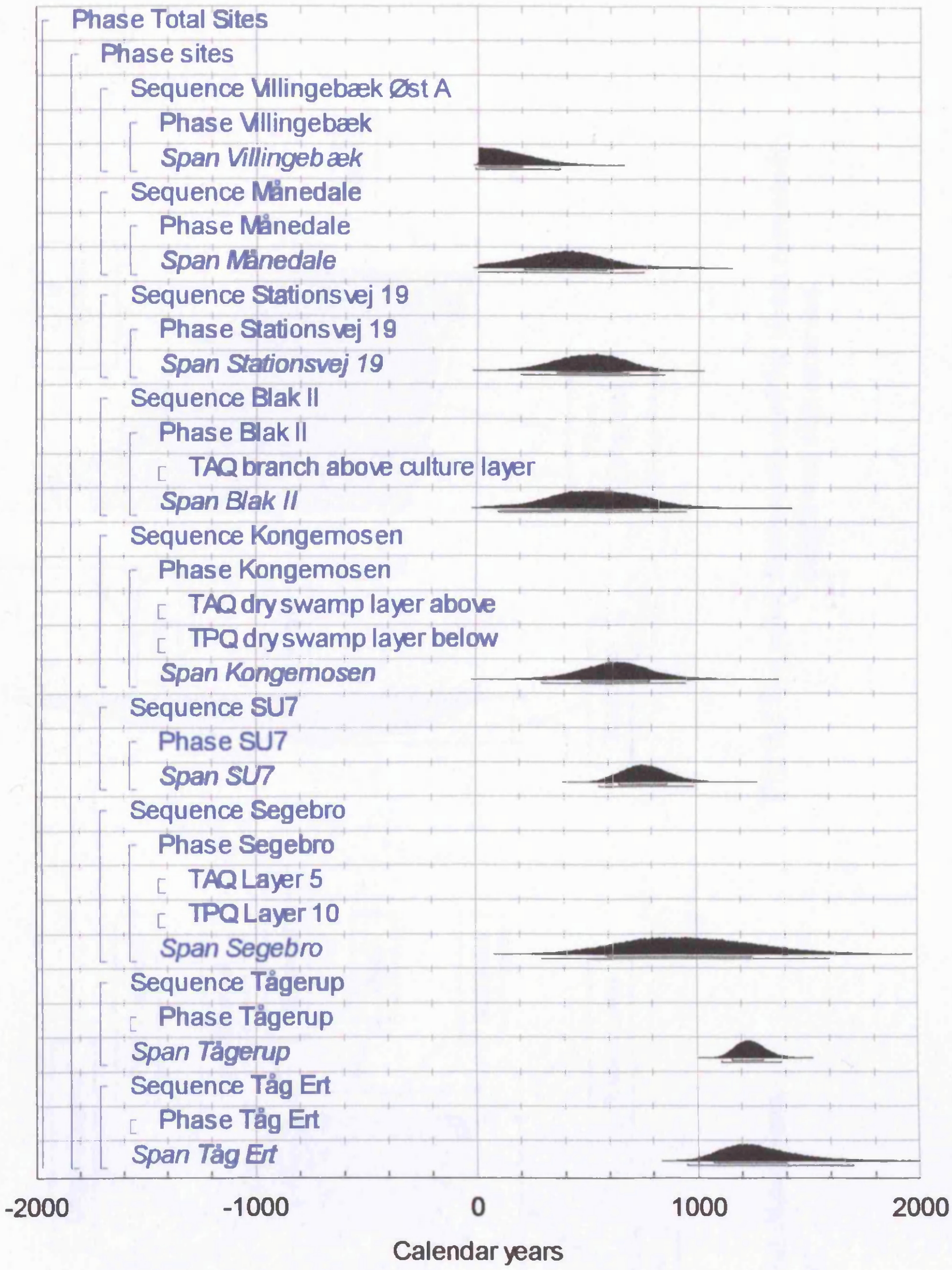


Fig. 4.13 Case-study chronological model showing phase duration probability distributions in calibrated calendar years.

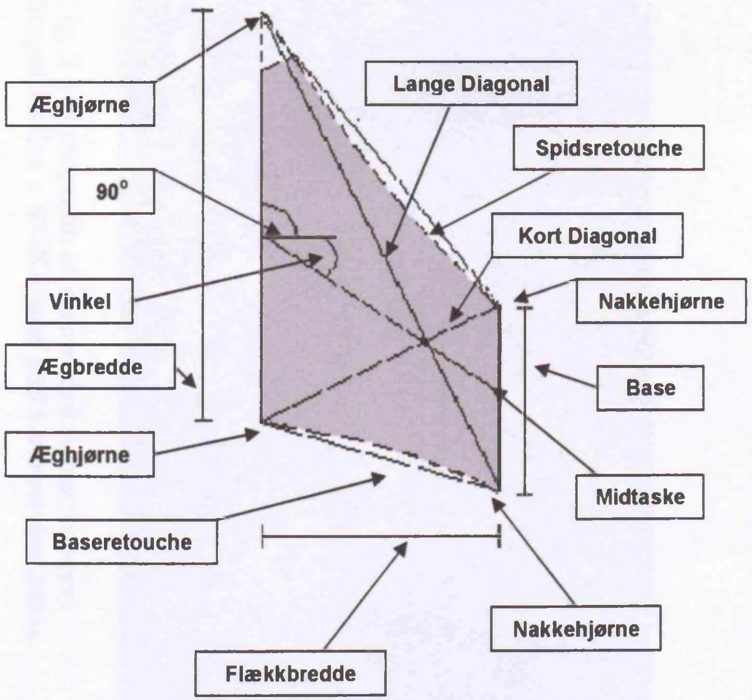


Figure 5.1 Vang Petersen's 1979 point dimensions, and terminology.

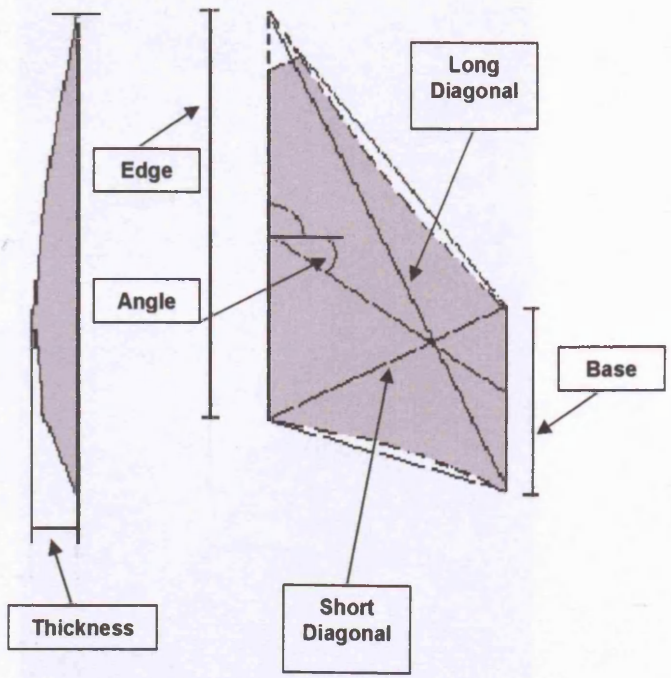


Fig. 5.2 The point dimensions used for thesis case-study; weight was also recorded.

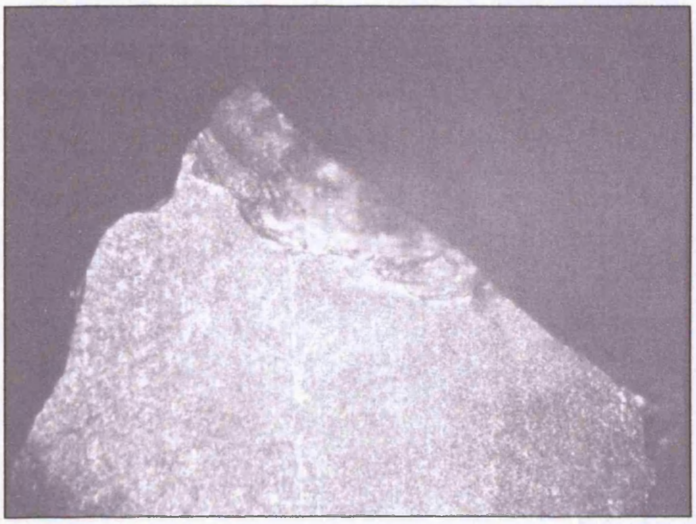


Fig. 5.3 Photograph of arrowhead base microwear. Magnification x 50 (Karsten and Knarrström 2003).

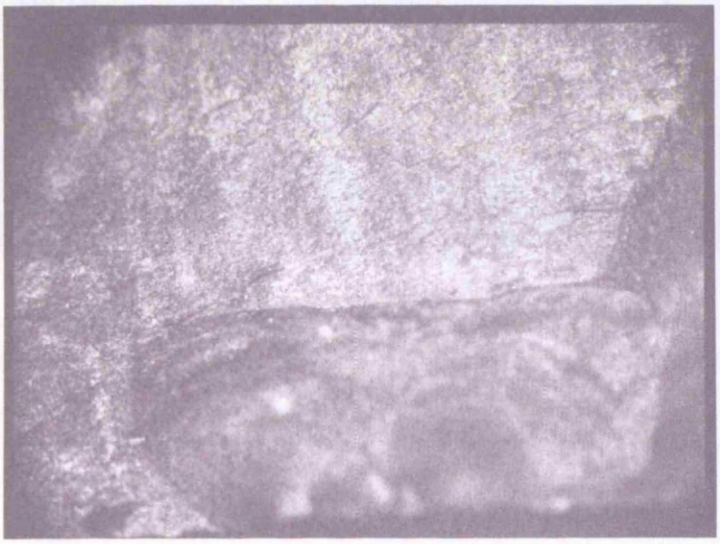


Fig. 5.4 Photograph of arrowhead tip microwear. Magnification x 50 (Karsten and Knarrström 2003).

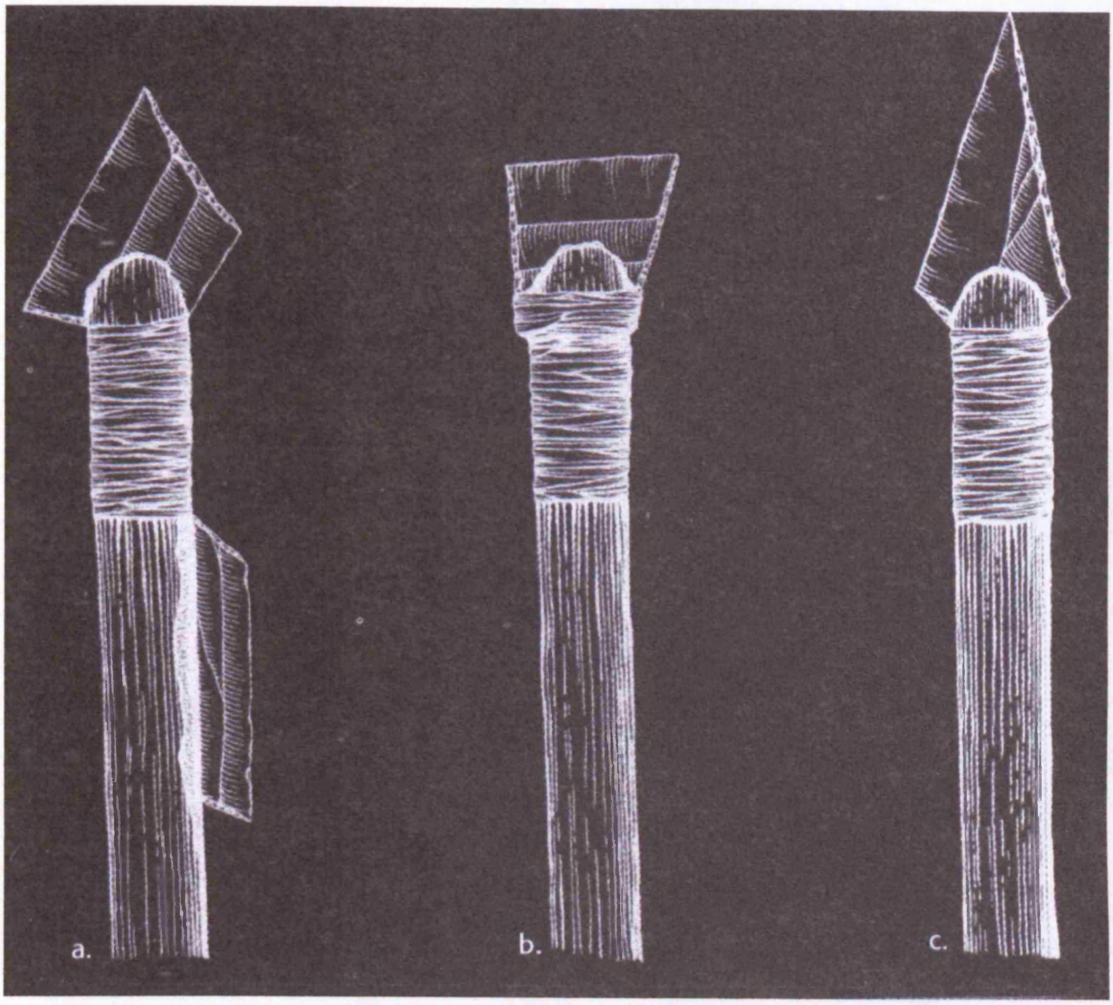


Fig. 5.5 Three methods of hafting Mesolithic arrowheads as proposed by Lars Larsson (see Karsten and Knarrström 2003).

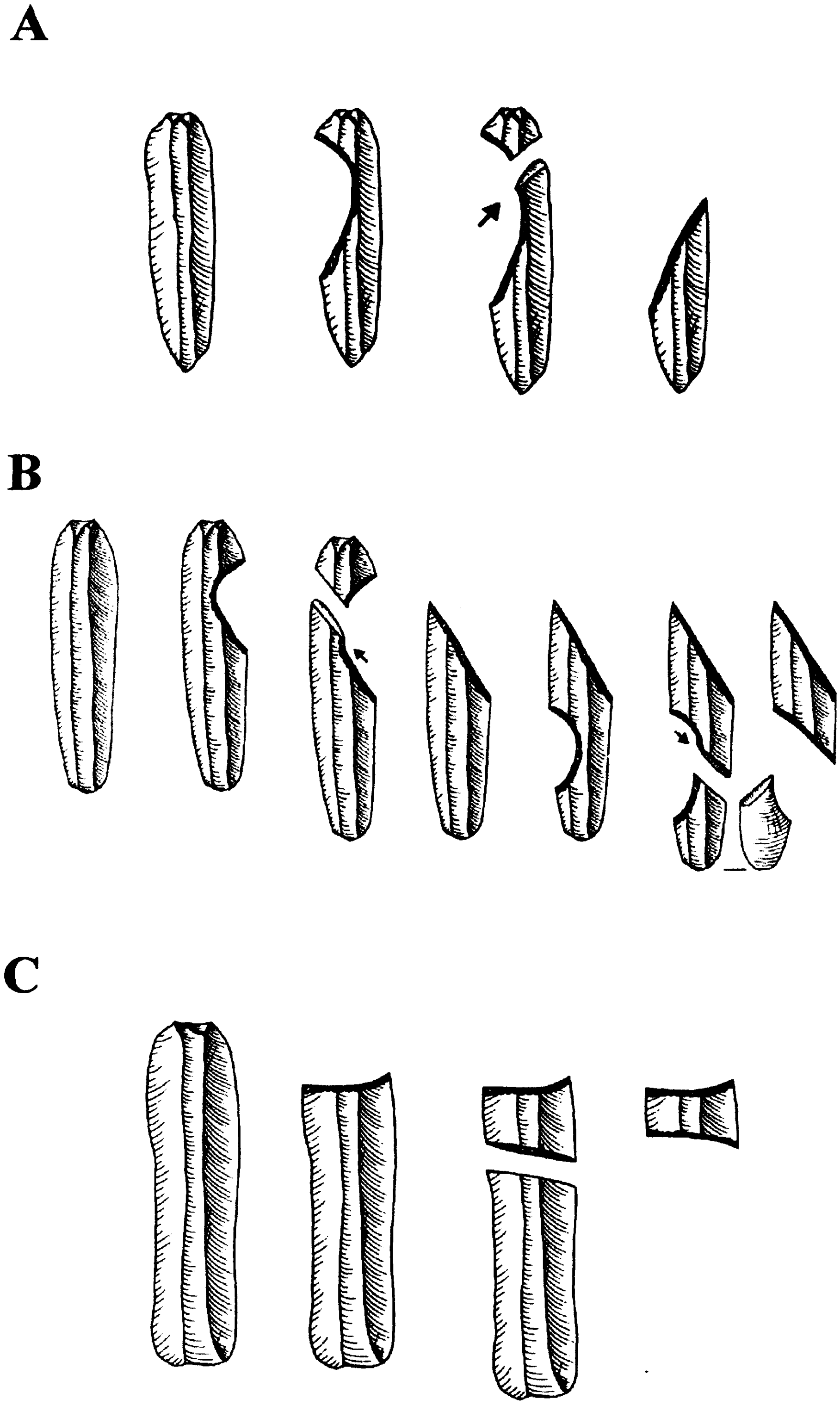
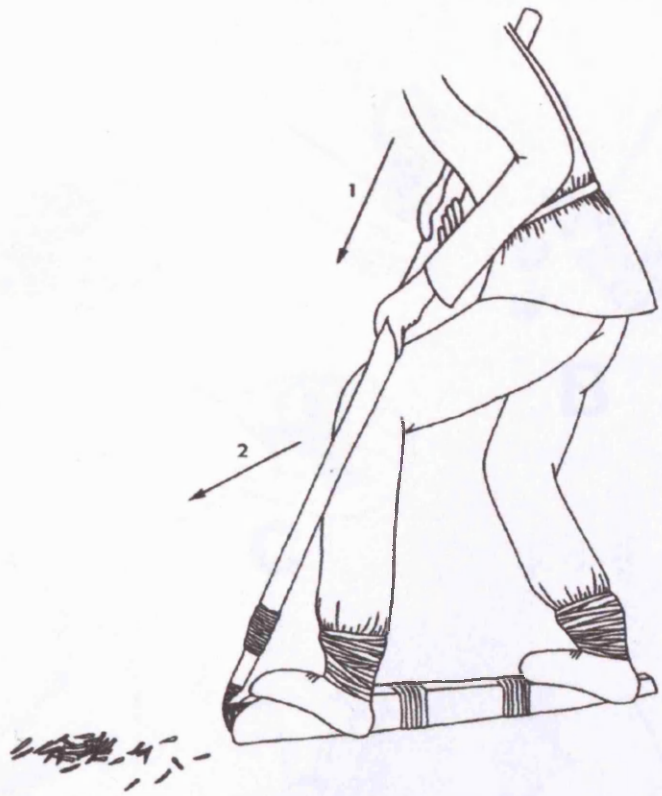


Fig. 5.6 lithic arrowhead reduction strategies (Vang Petersen 1999).

A



B

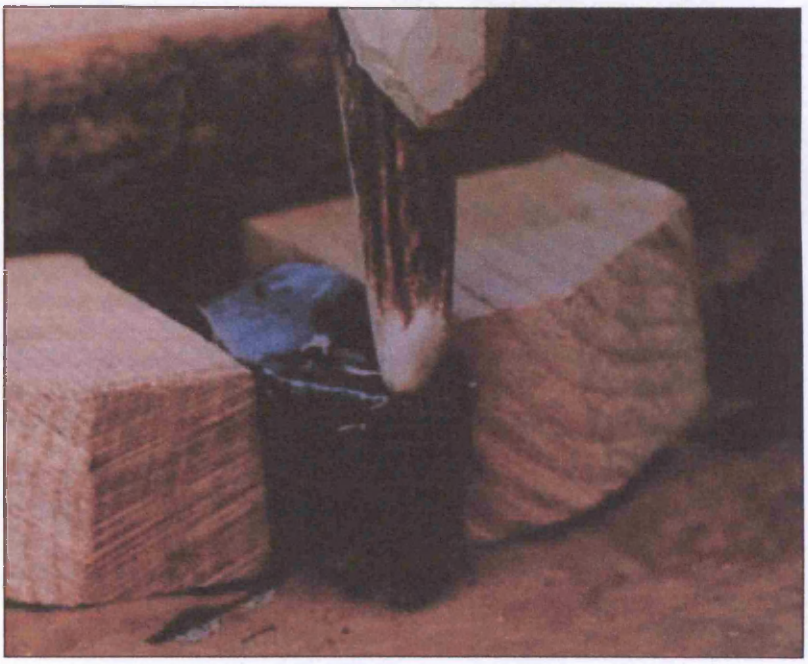


Fig. 5.7 Indirect blade punching, with an experimental reconstruction of the Tågerup pressure flaking tool and technique (Karsten and Knarrström 2003).

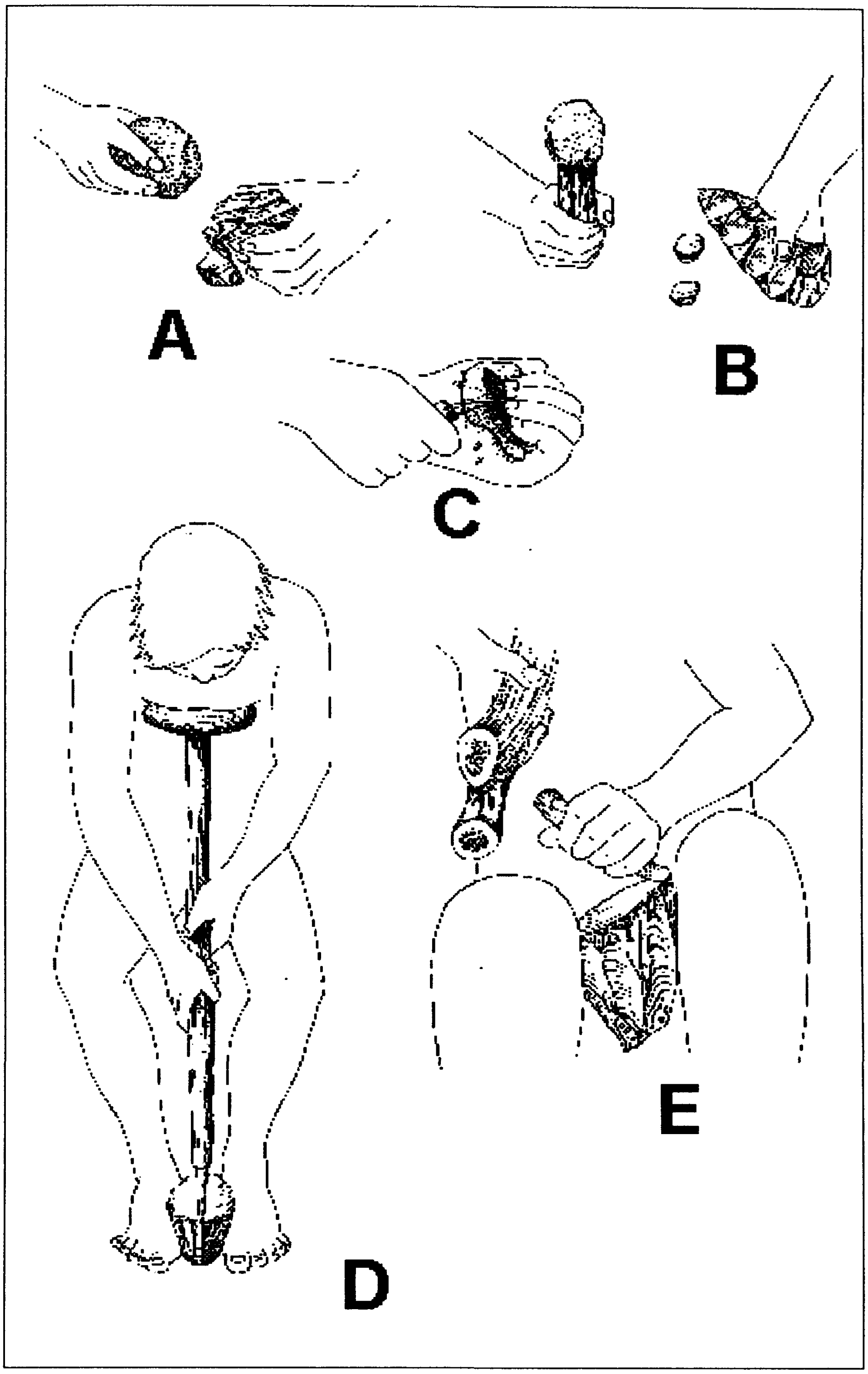


Fig. 5.8 different lithic techniques methods following Vang Petersen (1999).

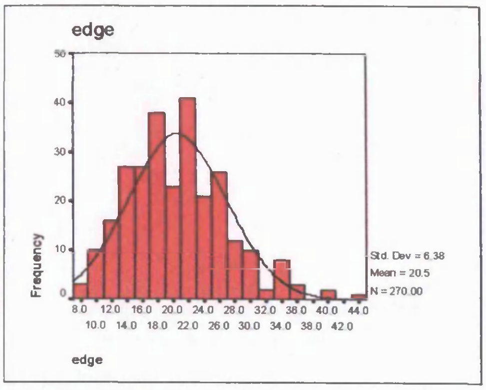


Figure 5.9 Edge

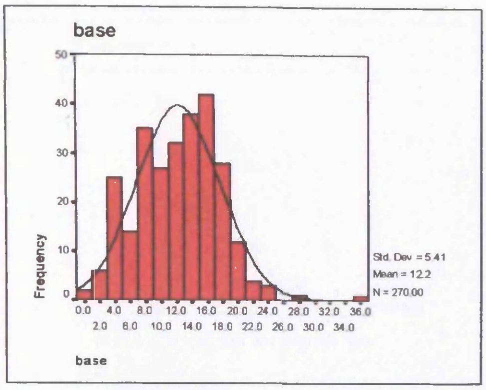


Figure 5.10 Base

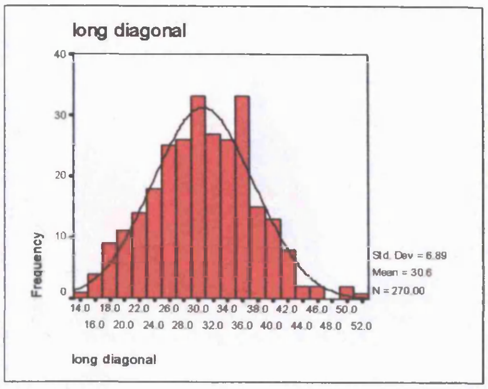


Figure 5.11 Long diagonal

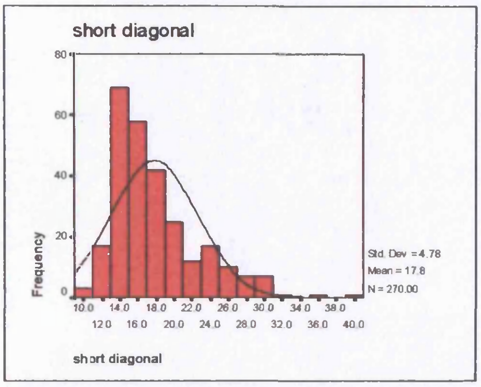


Figure 5.12 Short diagonal

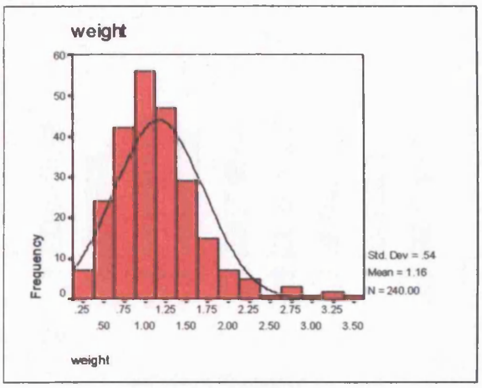


Figure 5.13 Weight

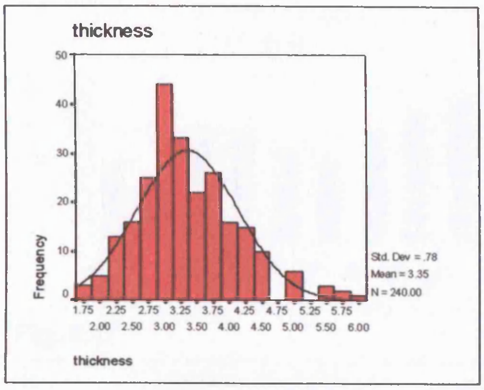


Figure 5.14 Thickness

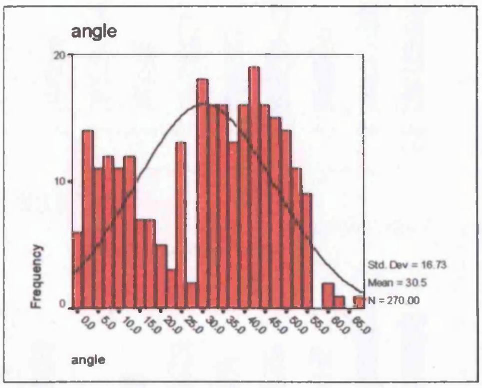


Figure 5.15 Angle

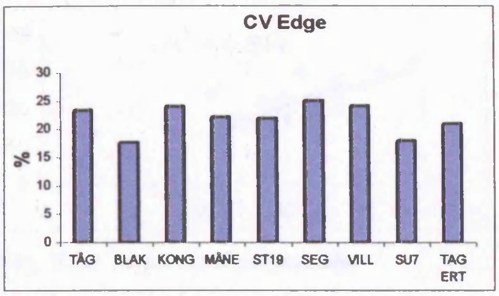


Fig. 5.16

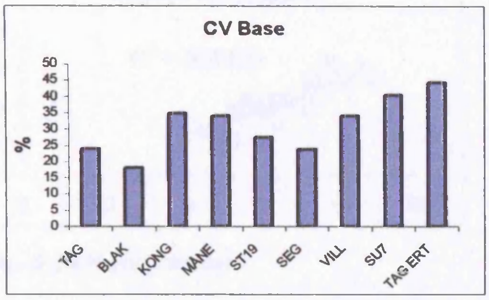


Fig. 5.17

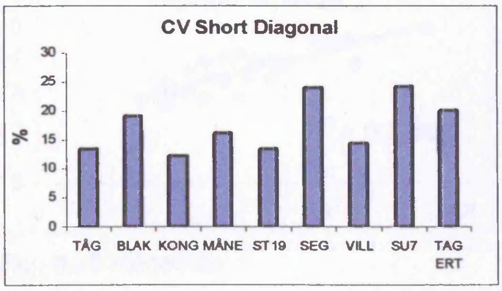


Fig. 5.18

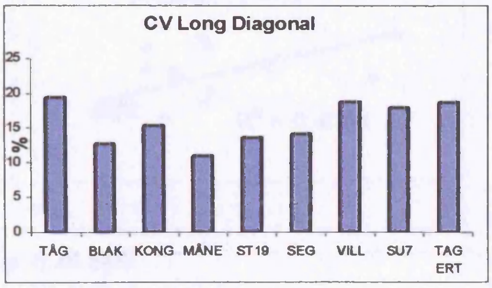


Fig. 5.19

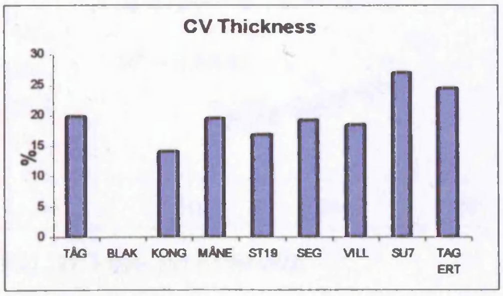


Fig. 5.20

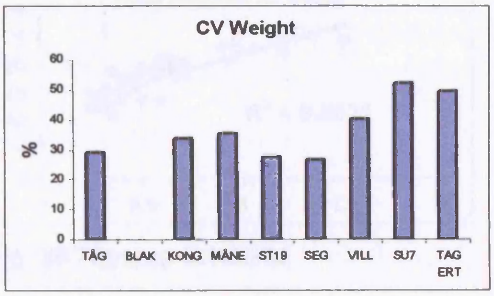


Fig. 5.21

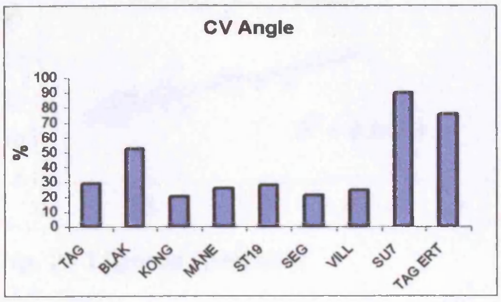


Fig. 5.22

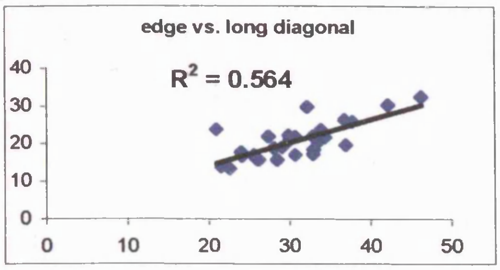


Fig. 5.23 Tågerup Kongemose

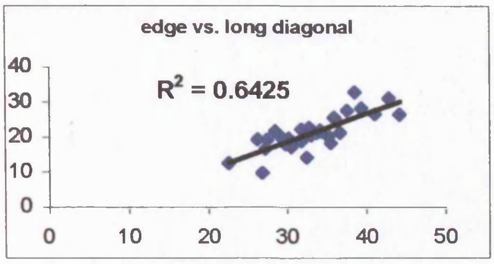


Fig. 5.24 Kongemose

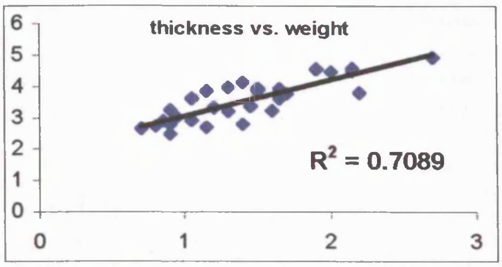


Fig. 5.25 Månedale

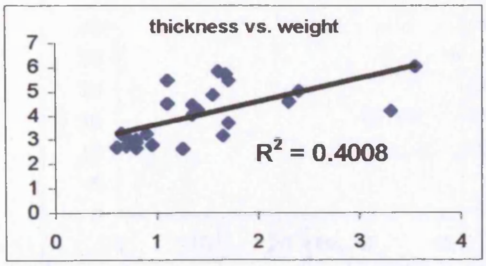


Fig. 5.26 SU7

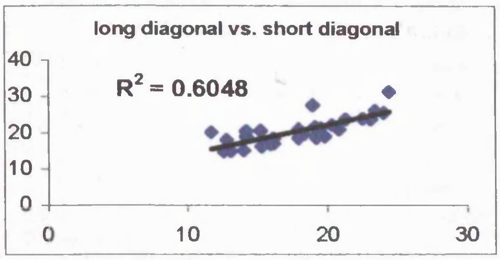


Fig. 27 Tågerup Ertebølle

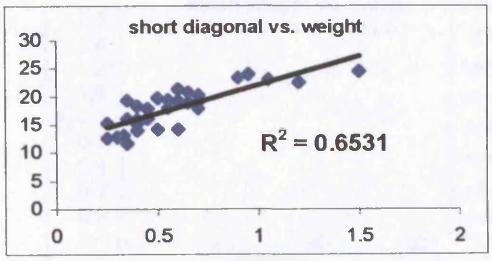


Fig. 28 Tågerup Ertebølle

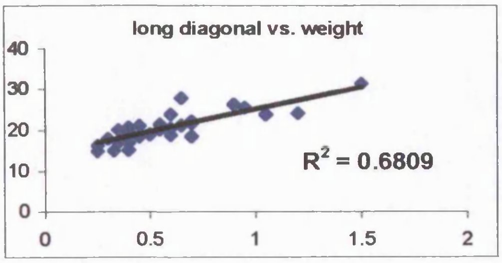


Fig. 29 Tågerup Ertebølle

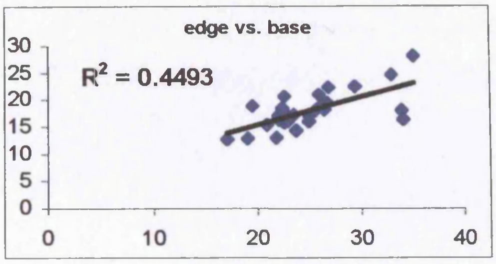


Fig. 30 Blak II

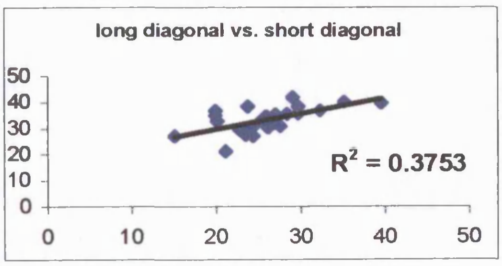


Fig. 31 Blak II

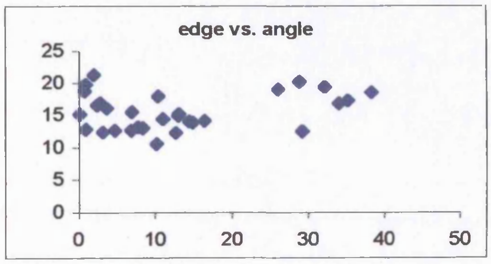


Fig. 32 SU7

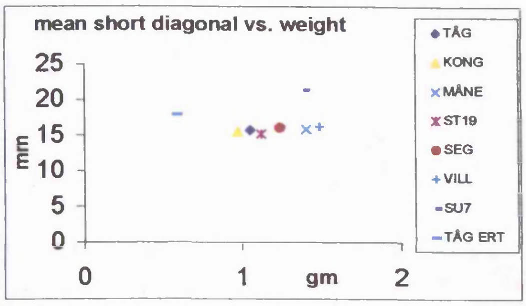


Fig. 5.33

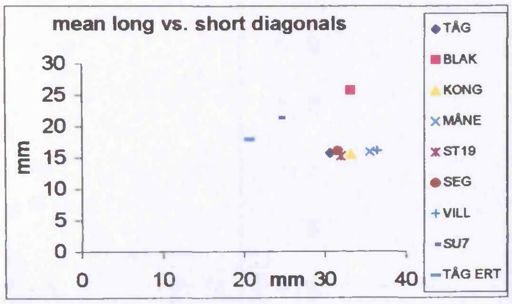


Fig. 5.34

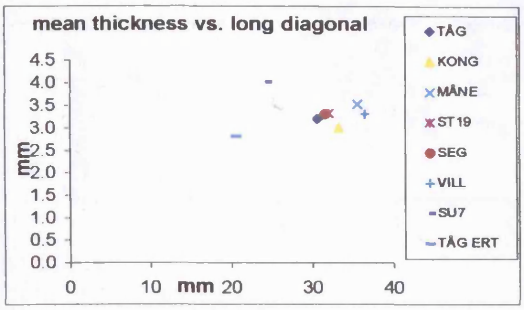


Fig. 5.35

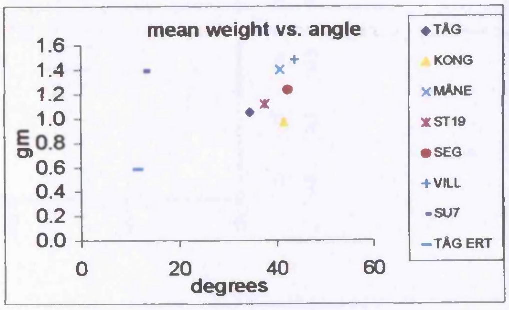
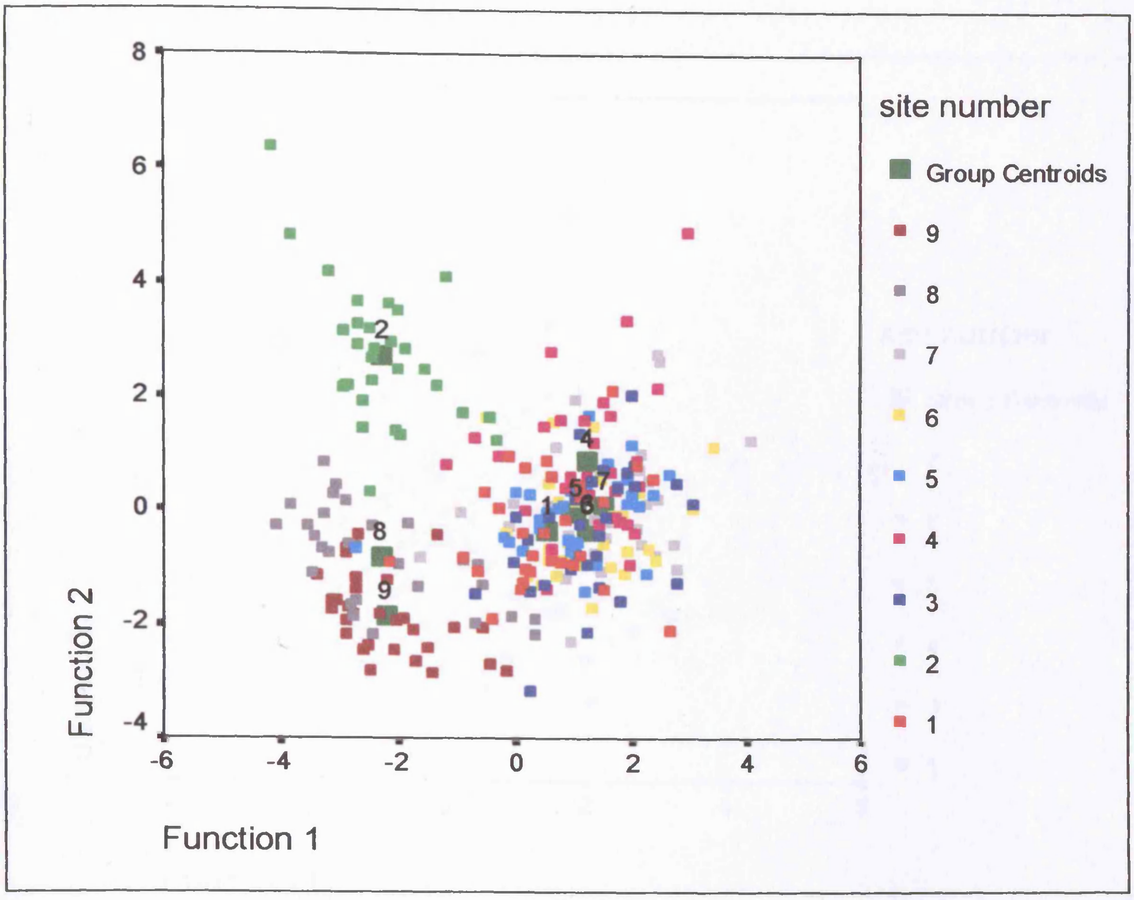


Fig. 5.36



5.37 Discriminant analysis scatterplot for all phases.

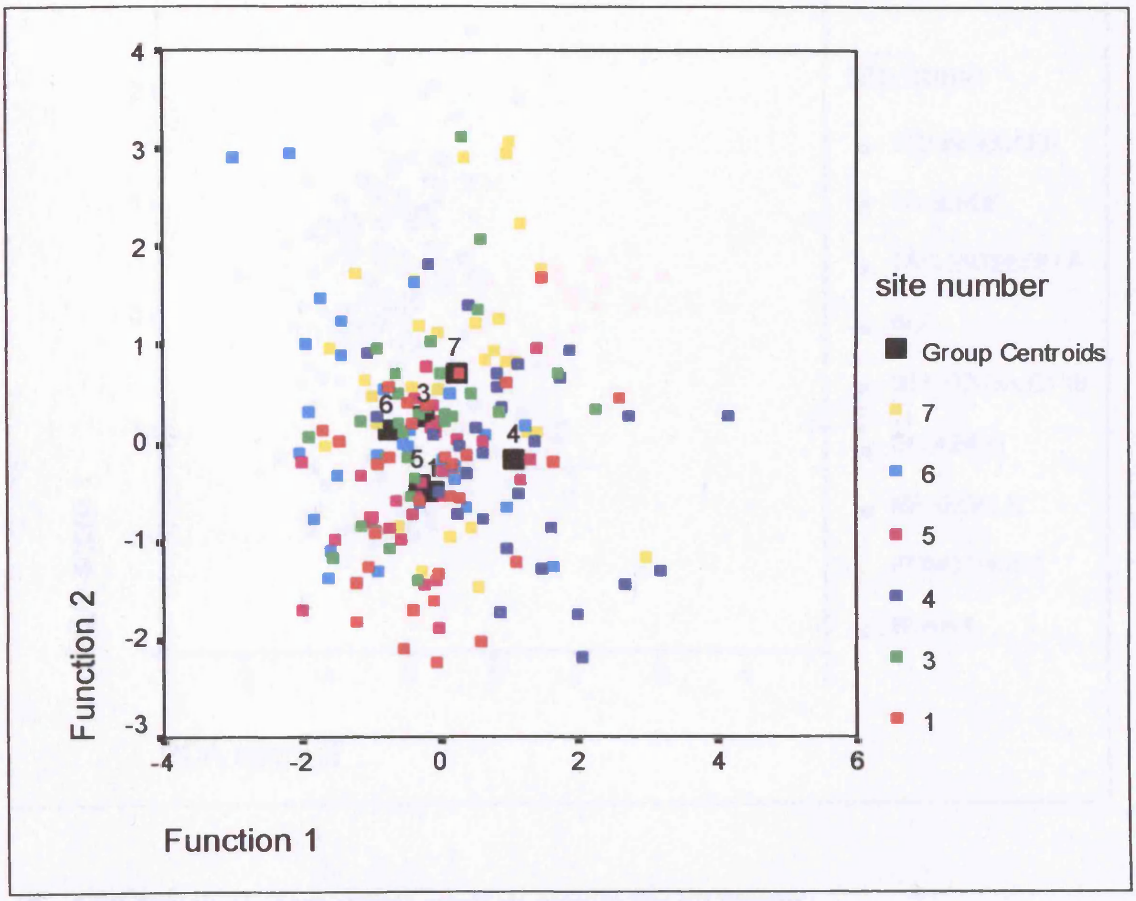


Fig. 5.38 Discriminant analysis scatterplot for main body of phases.

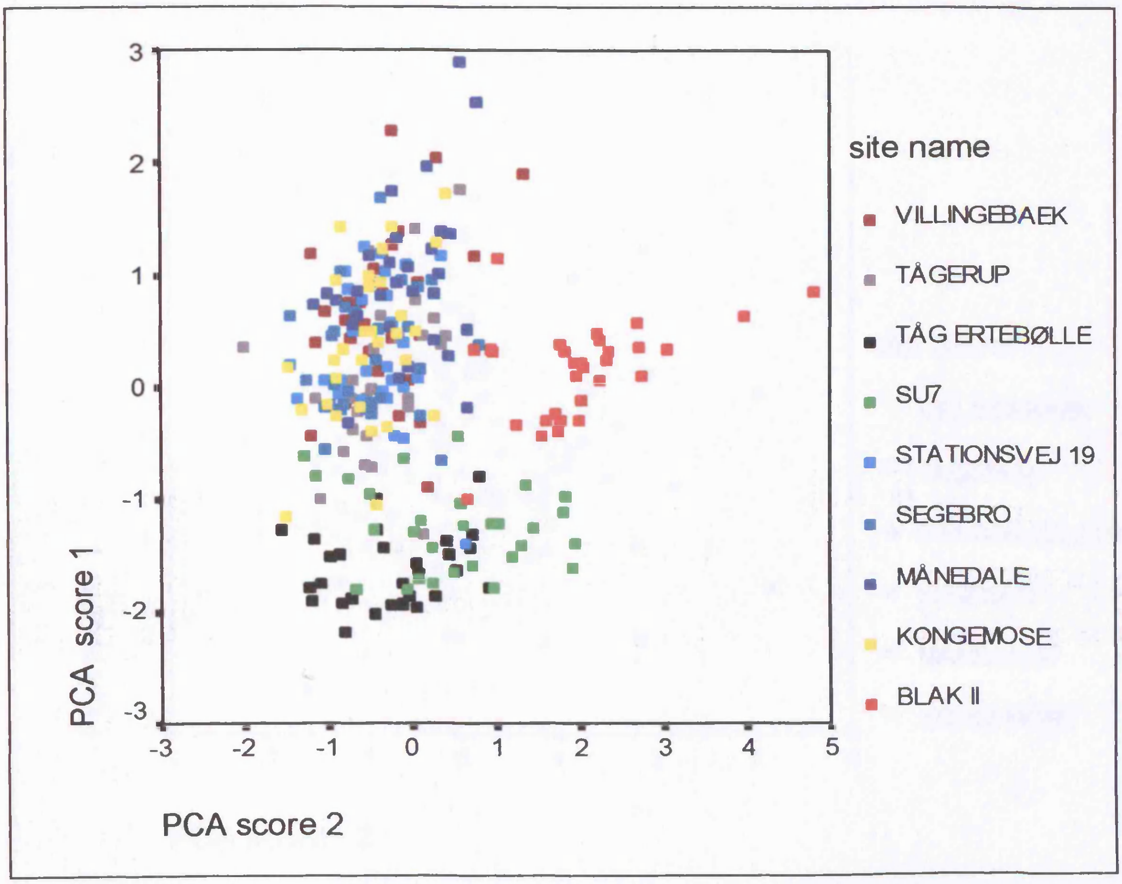


Fig. 5.39 Principal components analysis results for all phases.

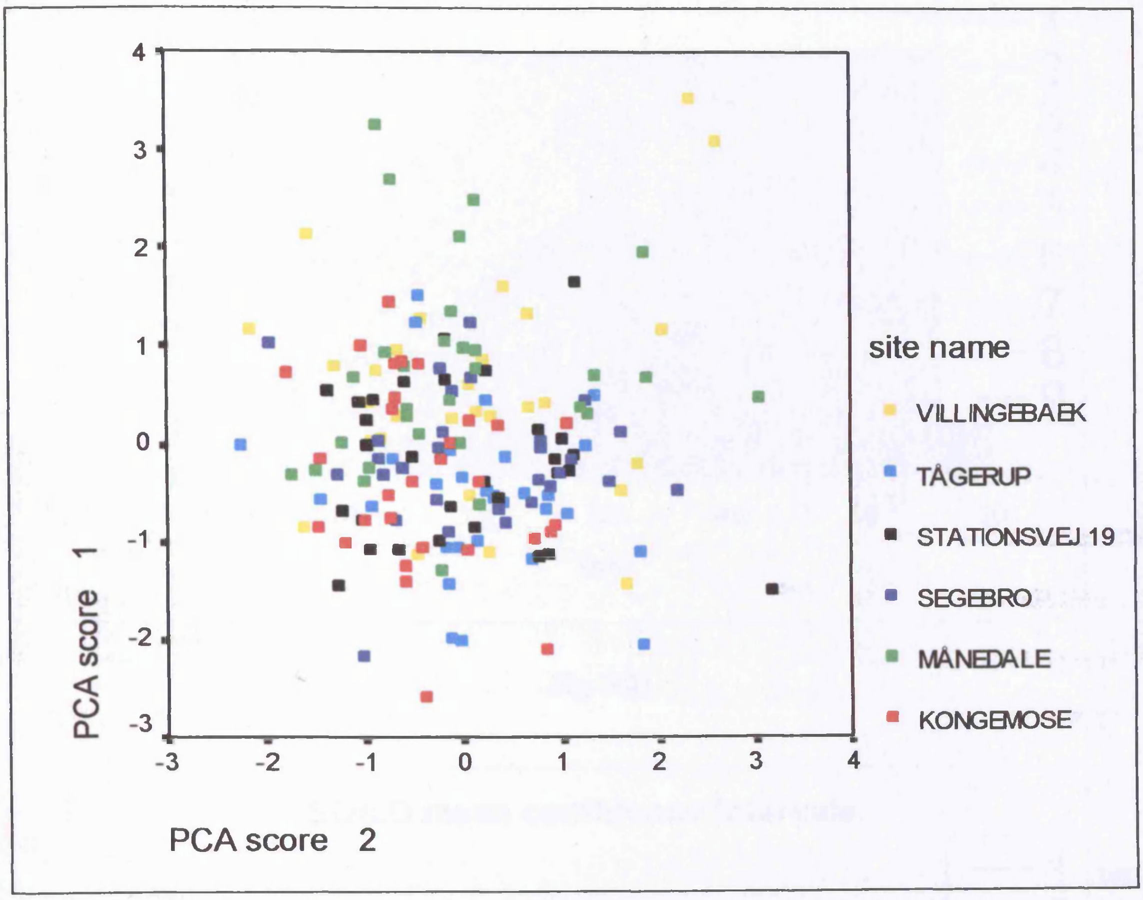


Fig. 5.40 Principal components analysis results for main body of phases.

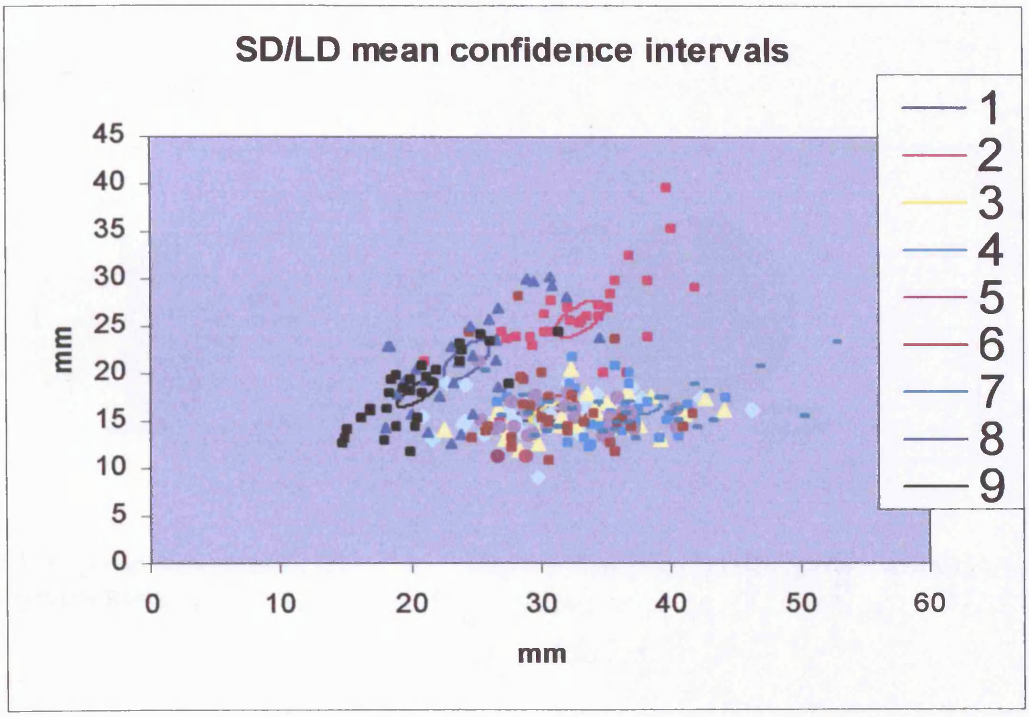


Fig. 5.41

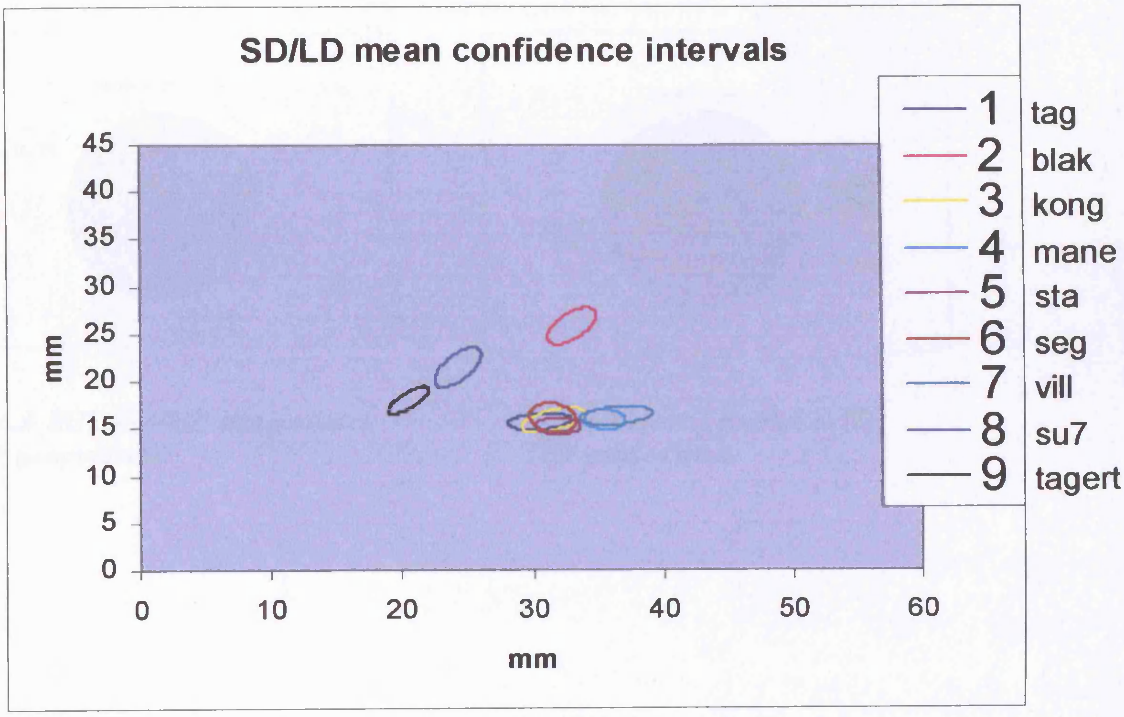
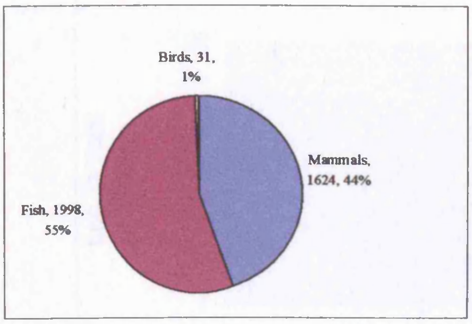


Fig. 5.42



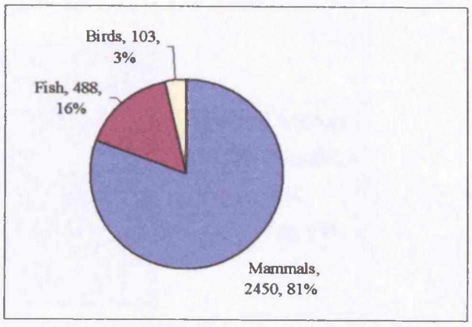
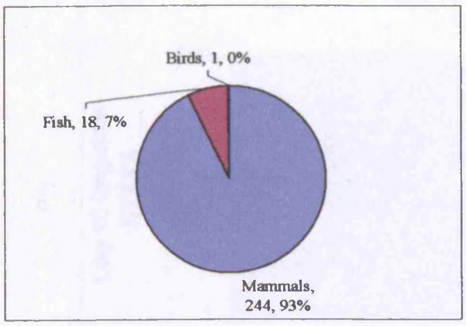


Fig. 6.1 Tågerup Kongemose: (1) NISP proportions.

Fig. 6.2. Segebro (6) NISP proportions.



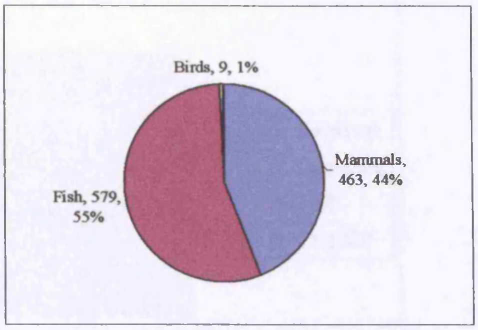


Fig. 6.3 SU7 (8) NISP proportions NISP proportions.

Fig. 6.4 Tågerup Ertebølle (9) NISP proportions.

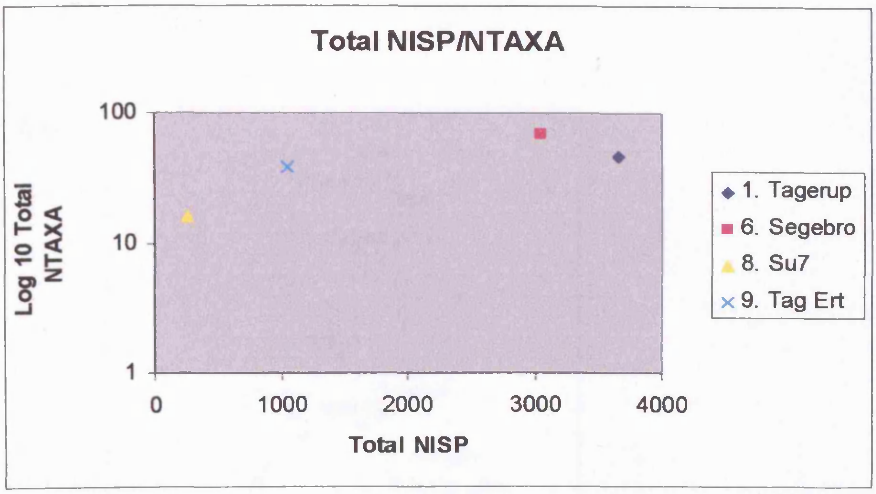


Fig. 6.5 Ungulate NTAXA vs. NISP. Following Grayson and Delpech 1998, this represents little difference in maximum diet breadth between assemblages.

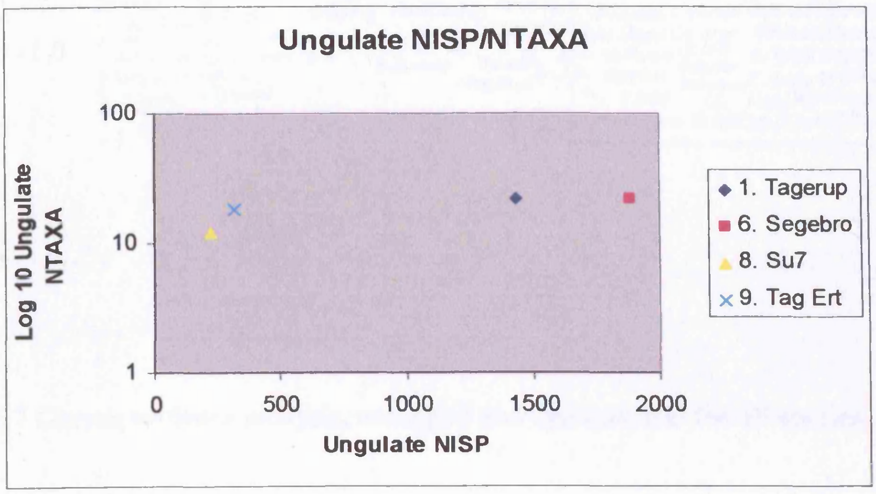


Fig. 6.6 Ungulate NTAXA vs. NISP. Following Grayson and Delpech (1998), this represents little difference between maximum diet breadth between ungulate assemblages.

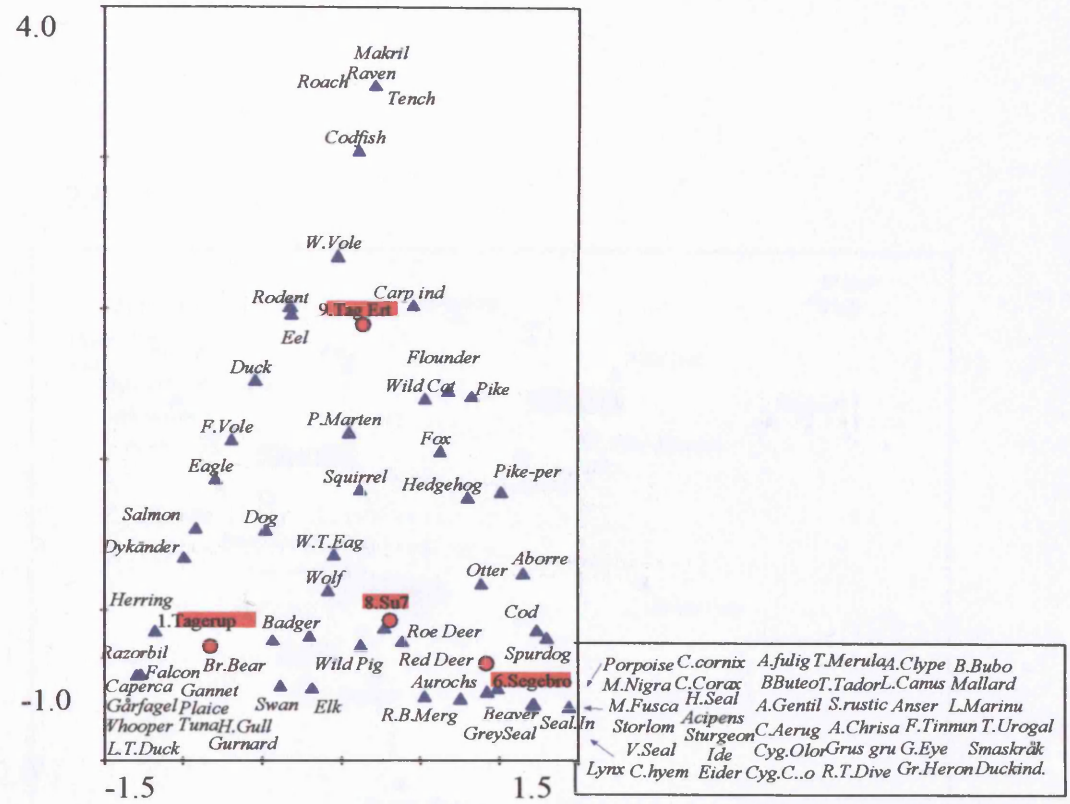


Fig. 6.7 Correspondence analysis, unlogged and symmetrical for all species.

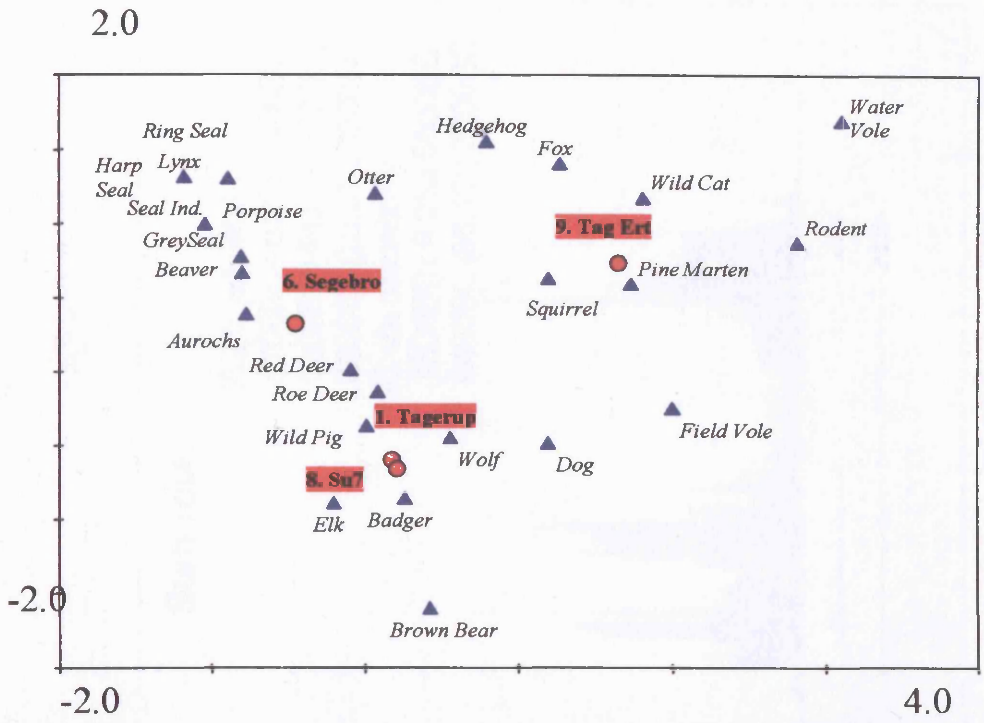


Fig. 6.8. Correspondence analysis – unlogged and symmetrical for all mammals.

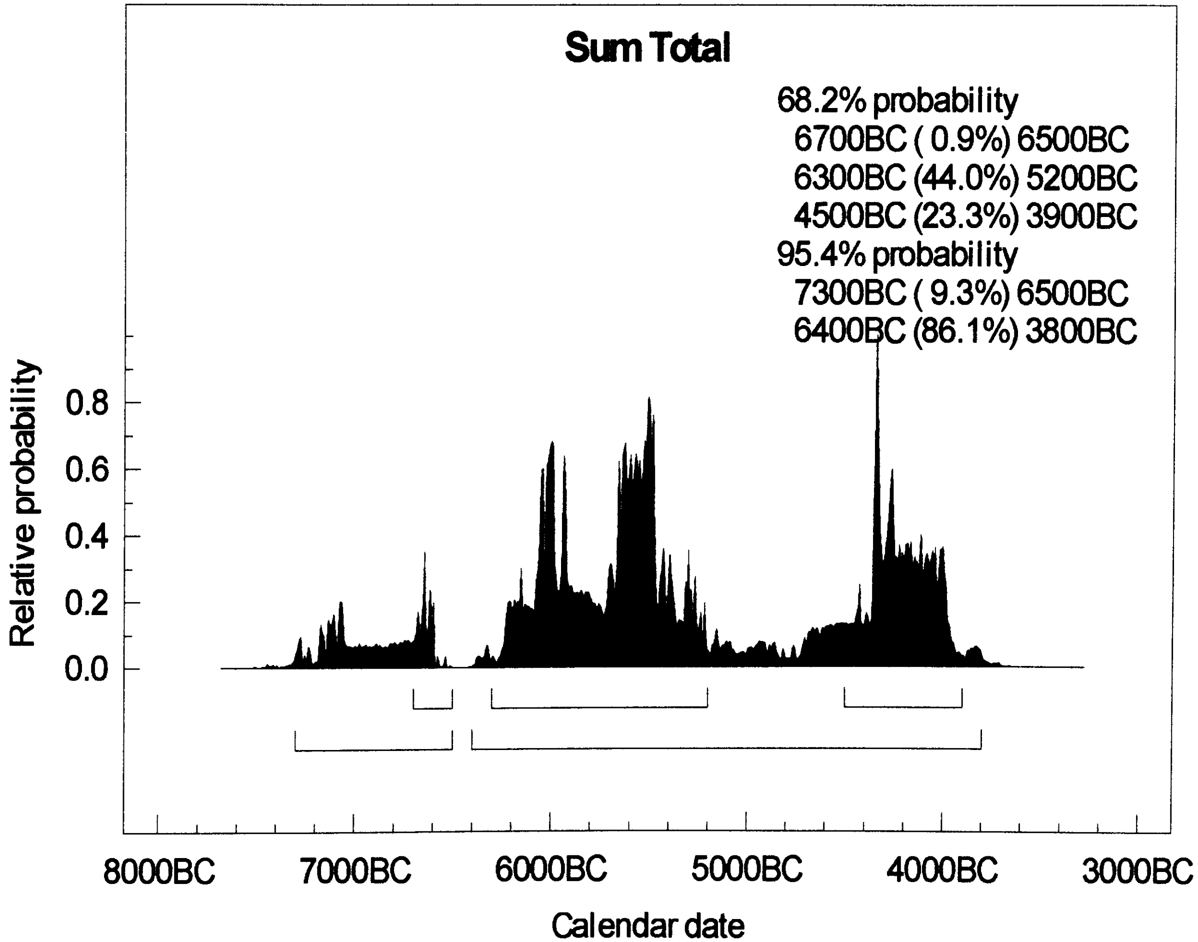


Fig. 6.9 Sum of the mean calibrated ^{14}C date for the 49 sites. Each sites' mean date was calculated using R_Combine, prior to using the Sum function.

This method reduces the bias inherent in using all radiometric data from sites with relatively large numbers of ^{14}C dates, such as the Tågerup phases.

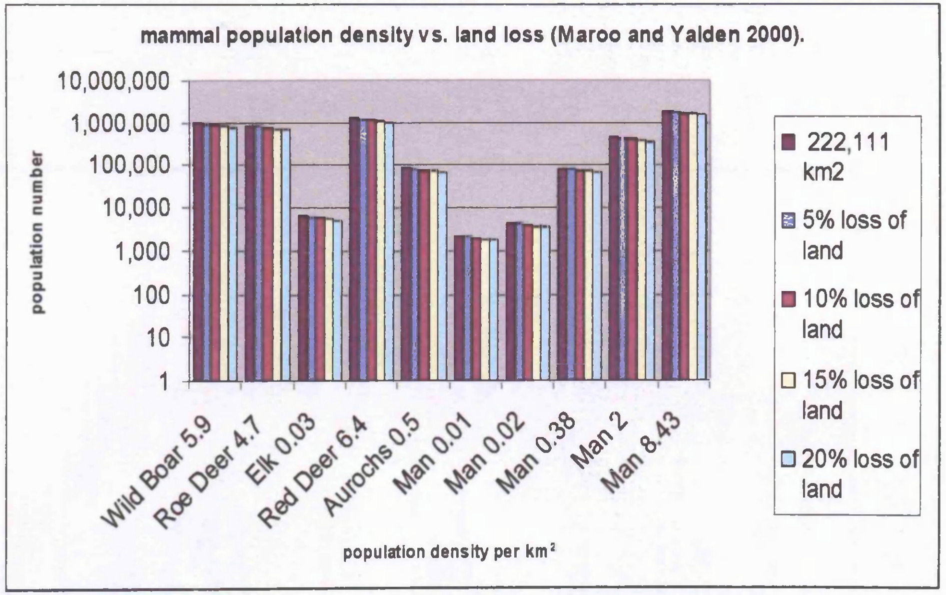


Fig. 6.10 Relative mammal population density vs. % land loss, based on the Mesolithic figures calculated for Great Britain at 7000 BP for a 222,111 km^2 land mass, following Maroo and Yalden (2000). This data has been supplemented with the different human population densities figures that are the subject of current debate (Karsten and Knarrström 2003). Please note aurochs and elk went extinct relatively quickly on the island of Zealand compared to the rest of the case study region (Aaris-Sørensen 1980).

Although a gross simplification, the land mass of the south Scandinavian case-study region is broadly comparable to Great Britain in both size, climate and flora throughout the 'Climatic Optimum', prior to the elm decline around 5000 BP. Localised processes of isostatic uplift and eustatic sea rise are highly complex (Christensen 1995), but its is posited that any overall reduction in available land mass (at an average of 2.5 cm per year from 6000 Cal BC to 4000 Cal BP), subsequent reduction in fodder and large ungulates in low level Southern Scandinavia, is offset by the increased number of marshes, estuaries, and related exploitation adaptations by the local population, characterized by the diverse Ertebølle period subsistence technologies (Price 1991).

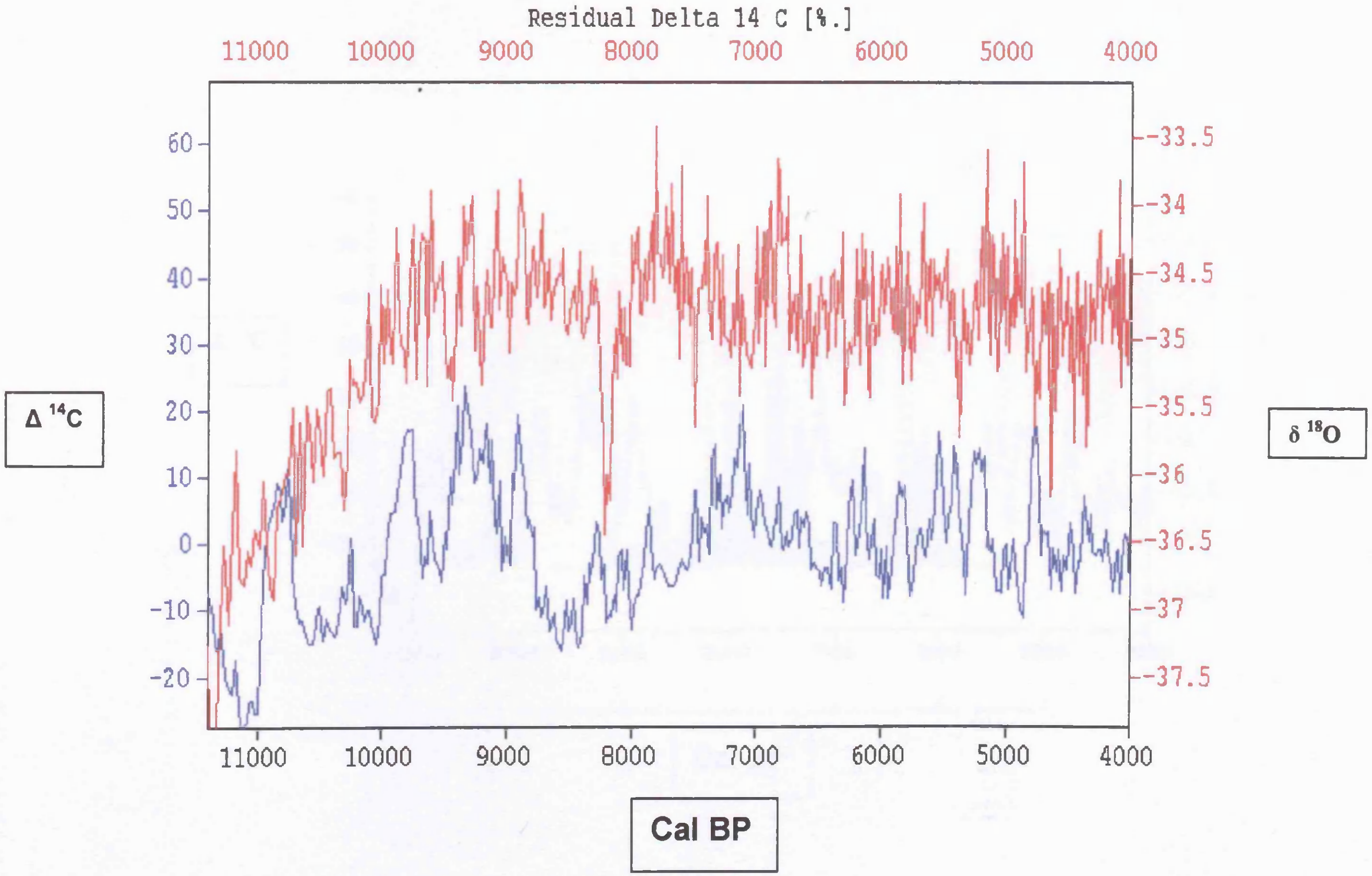


Fig. 7.11 Diagram showing two proxies for Holocene climate fluctuation. X axis in years BP. Upper plot in red = ^{18}O isotope data is taken as a proxy of atmospheric precipitation/temperature. Lower plot in blue = residual $\Delta\ ^{14}C$ is used as a proxy for temperature change, caused by fluctuating solar winds and solar activity.

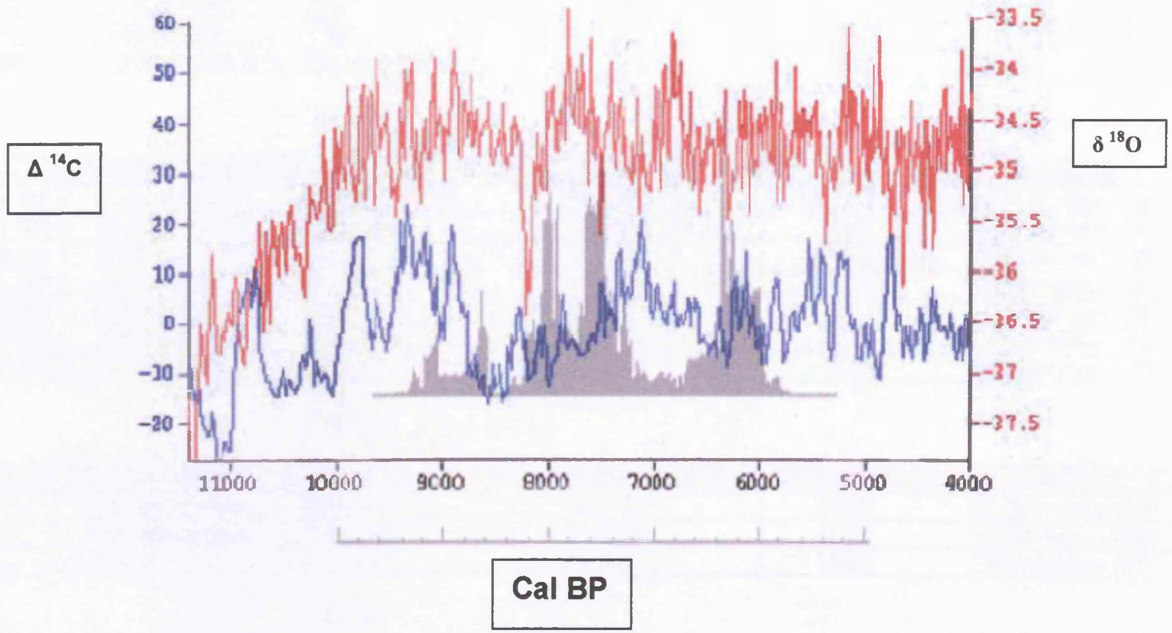


Fig. 6.12 Environmental proxies superimposed onto the population hypothesis plot. X axis in calibrated calendar years BP. Note the population trough at 8500 BP coincides with a big dip in the upper red $\delta\ ^{18}O$ curve, and a peak in the lower blue $\Delta\ ^{14}C$ plot. This is interpreted as a relatively cold and wet period, unfavorable for the human food chain. The following period sees an increase in temperature and an increasingly drier period, with a dramatic increase in population.

Site	Layer/context	Sample	Sample Ref. #	BP	+/ - Error	Reference
Kongemosen	Above culture layer	Swamp peat	K-1527	6820	120	Sørensen 1996
Kongemosen	Culture layer	Hazelnut	K-1528	7560	120	Sørensen 1996
Kongemosen	Culture layer	Bark	K-1588	7280	130	Sørensen 1996
Kongemosen	Refuse layer	Bark	K-1589	7350	150	Sørensen 1996
Kongemosen	Under culture layer	Swamp peat	K-1526	7840	140	Sørensen 1996

Tab. 4.1

Site	Layer/context	Sample	Sample Ref. #	BP	+/ - Error	Reference
Villingebæk Øst A	Culture layer	Wood	K-1368	7280	120	Sørensen 1996
Villingebæk Øst A	Culture layer	Charcoal	K-1369	7040	120	Sørensen 1996
Villingebæk Øst A	Fish trap	Wood	K-1486	7030	130	Sørensen 1996
Villingebæk Øst A	Refuse layer	Wood	K-1334	7220	120	Sørensen 1996
Villingebæk Øst A	Refuse layer	Wood	K-1370	7070	120	Sørensen 1996
Villingebæk Øst A	Refuse layer	Wood	K-1371	7090	120	Sørensen 1996
Villingebæk Øst A	Refuse layer	Wood	K-1372	7120	120	Sørensen 1996

Tab. 4.2

Site	Layer/context	Sample	Sample Ref. #	BP	+/ - Error	Reference
Månedale	settlement layer	Charcoal	K-1826	7150	120	Sørensen 1996
Månedale	settlement layer	Charcoal	K-1825	7040	120	Sørensen 1996
Månedale	grave	Charcoal	K-1827	7530	130	Sørensen 1996

Tab. 4.3

Site	Layer/context	Sample	Sample Ref. #	BP	+/ - Error	Reference
Stationsvej 19	Pit - culture layer N	Charcoal	K-4959	7410	110	Sørensen 1996
Stationsvej 19	Grave with burnt ston	Charcoal	K-4714	6820	105	Sørensen 1996
Stationsvej 19	Packed sludge layer	Charcoal	K-4960	6130	100	Brinch Petersen Pers. Com.
Stationsvej 19	Layer 5	Charcoal	K-4962	5990	90	Brinch Petersen Pers. Com.
Stationsvej 19	Bronze Age fireplace	Charcoal	K-4961	3100	95	Brinch Petersen Pers. Com.

Tab. 4.4

Site	Layer/context	Sample	Sample Ref. #	BP	+/ - Error	Reference
Blak II	Above culture layer	Tree branch	K-5834	7460	115	Sørensen 1996
Blak II	Culture layer	Charcoal	K-5662	7280	110	Sørensen 1996
Blak II	Culture layer	Tree stump	K-5663	7490	110	Sørensen 1996
Blak II	Culture layer	Charcoal	K-5833	7280	90	Sørensen 1996
Blak II	Culture layer	Oak stick	K-5835	7160	120	Sørensen 1996
Blak II	Culture layer	Bone	K-5836	6710	175	Sørensen 1996
Blak II	Culture layer	Human jaw bone	Ka-6454	7440	90	Sørensen 1996

Tab. 4.5

Site	Layer/context	Sample	Sample Ref. #	BP	+/ - Error	Reference
Segebro	11	Charcoal	St-812	6310	280	Larsson 1982
Segebro	7	Bone	Lu-855:2	7140	80	Larsson 1982
Segebro	7	Bone	Lu-854	7080	80	Larsson 1982
Segebro	7	Bone	Lu-855:1	7030	80	Larsson 1982
Segebro	6	Charcoal	Lu-626	7390	80	Larsson 1982
Segebro	6	Charcoal	Lu-759	7320	130	Larsson 1982
Segebro	6	Charcoal	Lu-1501	7140	75	Larsson 1982
Segebro	6	Charcoal	Lu-758	6970	90	Larsson 1982
Segebro	5	Charcoal	St-1195	7125	90	Larsson 1982

Tab. 4.6

Site	Layer/context	Sample	Sample Ref. #	BP	+/ - Error	Reference
Tågerup	6	Bone (animal)	Ua-9936	6785	60	Karsten and Knarrström 2001
Tågerup	6	Bone (animal)	Ua-9938	7290	75	Karsten and Knarrström 2001
Tågerup	6	Bone (animal)	Ua-25191	5700	70	Karsten and Knarrström 2001
Tågerup	6	Bone (animal)	Ua-25195	7335	85	Karsten and Knarrström 2001
Tågerup	6	Bone (animal)	LuA-4637	6700	110	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-9937	7345	60	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-9939	7470	80	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-9940	7610	85	Karsten and Knarrström 2001
Tågerup	4a	Bone (animal)	Ua-9941	7480	80	Karsten and Knarrström 2001
Tågerup	4b	Bone (animal)	Ua-9942	7615	90	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-9943	7435	85	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-9944	7810	95	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-9956	7355	75	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25186	7430	65	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25187	7605	65	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25188	7510	65	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25189	7645	80	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25190	7355	65	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25192	7440	65	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25193	5070	70	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25194	7670	75	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25196	7140	65	Karsten and Knarrström 2001
Tågerup	4	Bone Human Femur	Ua-25197	7415	80	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25198	7740	80	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25199	7440	80	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25200	7760	65	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25201	7595	70	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25202	7420	65	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25203	7385	80	Karsten and Knarrström 2001

Tab. 4.7A

Site	Layer/context	Sample	Sample Ref. #	BP	+/ - Error	Reference
Tågerup	4	Bone (animal)	Ua-25204	7405	85	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25205	7745	65	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25206	8095	90	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25207	7470	90	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25208	7225	75	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25209	7430	80	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25210	6690	80	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25211	7225	65	Karsten and Knarrström 2001
Tågerup	4c	Bone (animal)	Ua-25212	7575	75	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25213	7515	80	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25214	6770	70	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25215	7415	60	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	Ua-25216	7185	60	Karsten and Knarrström 2001
Tågerup	4	Bone (animal)	LuA-4638	7260	100	Karsten and Knarrström 2001
Tågerup	2	Wood	Ua-9951	6880	65	Karsten and Knarrström 2001
Tågerup	G1 A6258	Charcoal	Ua-25470	3750	75	Karsten and Knarrström 2001
Tågerup	G5 A17779	Charcoal	Ua-9945	7245	60	Karsten and Knarrström 2001
Tågerup	111 Fu	Charcoal	Ua-8365	7380	90	Karsten and Knarrström 2001
Tågerup	108 Fu	Charcoal	Ua-8635	7460	70	Karsten and Knarrström 2001
Tågerup	110 Fu	Charcoal	Ua-8635a	7270	65	Karsten and Knarrström 2001
Tågerup	114 Fu	Charcoal	Ua-9180	6760	75	Karsten and Knarrström 2001

Tab. 4.7B

Site	Layer/context	Sample	Sample Ref. #	BP	+/ - Error	Reference
Tågerup Ertebølle	6	Wood	Ua-9947	6490	75	Karsten and Knarrström 2001
Tågerup Ertebølle	6	Arrow Shaft	Ua-9948	6550	70	Karsten and Knarrström 2001
Tågerup Ertebølle	6	Wood	Ua-9949	6655	70	Karsten and Knarrström 2001
Tågerup Ertebølle	6	Wood	Ua-9950	6440	75	Karsten and Knarrström 2001
Tågerup Ertebølle	6	Wood	Ua-9952	6420	80	Karsten and Knarrström 2001
Tågerup Ertebølle	6	Wood	Ua-9953	6365	75	Karsten and Knarrström 2001
Tågerup Ertebølle	6	Wood	Ua-9954	6485	90	Karsten and Knarrström 2001
Tågerup Ertebølle	6	Wood	Ua-9955	6460	70	Karsten and Knarrström 2001
Tågerup Ertebølle	6	Bone (animal)	Ua-9936	6785	60	Karsten and Knarrström 2001
Tågerup Ertebølle	6	Bone (animal)	Ua-9938	7290	75	Karsten and Knarrström 2001
Tågerup Ertebølle	6	Bone (animal)	Ua-25191	5700	70	Karsten and Knarrström 2001
Tågerup Ertebølle	6	Bone (animal)	Ua-25195	7335	85	Karsten and Knarrström 2001
Tågerup Ertebølle	6	Bone (animal)	LuA-4637	6700	110	Karsten and Knarrström 2001
Tågerup Ertebølle	Grave 4	Charcoal	Ua-25218	5820	100	Karsten and Knarrström 2001
Tågerup Ertebølle	Grave 4	Charcoal	Ua-25471	5845	80	Karsten and Knarrström 2001
Tågerup Ertebølle	Grave 4	Charcoal	Ua-25472	6955	80	Karsten and Knarrström 2001

Tab. 4.8

Site	Layer/context	Sample	Sample Ref. #	BP	+/ - Error	Reference
SU7	22	Bone (animal)	Ua-25116	5905	75	Karsten and Knarrström 2001
SU7	22	Bone (animal)	Ua-25117	6505	75	Karsten and Knarrström 2001
SU7	22	Charcoal	Ua-25118	6700	85	Karsten and Knarrström 2001
SU7	A1556	Nut shell	Ua-25119	6440	85	Karsten and Knarrström 2001
SU7	22	Bone (animal)	Ua-25184	6370	60	Karsten and Knarrström 2001
SU7	103Fu	Bone (animal)	Ua-25185	6025	55	Karsten and Knarrström 2001
SU7	20	Charcoal	Ua-8369	6315	65	Karsten and Knarrström 2001
SU7	22	Charcoal	Ua-8370	6375	70	Karsten and Knarrström 2001

Tab. 4.9

SITE 1	POINT ID	FIND NUMBER	EDGE	BASE	LONG DIAGONAL	SHORT DIAGONAL	WEIGHT	THICKNESS	ANGLE	PCA Comp. 1	PCA Comp. 2	DA Func. 1	DA Func. 2
Tågerup	TÅG 1	12304	21.00	9.80	30.00	15.10	1.35	3.36	32.10	-0.07	-0.49	0.28	-0.76
Tågerup	TÅG 2	17418	23.70	12.60	21.00	15.40	1.35	3.38	41.50	-0.08	-0.70	0.13	-0.37
Tågerup	TÅG 3	16314	26.40	16.70	36.80	14.90	0.80	1.78	52.70	1.25	-0.53	2.38	0.56
Tågerup	TÅG 4	12560	22.10	8.30	29.90	9.00	0.90	3.33	55.70	0.36	-1.96	2.64	-2.11
Tågerup	TÅG 5	12748	29.80	12.30	32.20	19.00	0.60	3.36	38.50	0.67	0.26	0.16	0.79
Tågerup	TÅG 6	10455	19.70	16.90	37.00	18.50	1.20	4.37	29.40	0.50	0.39	0.55	0.89
Tågerup	TÅG 7	9626	18.40	10.00	33.00	16.20	1.55	3.99	35.90	0.00	-0.45	0.76	-0.89
Tågerup	TÅG 8	21300	30.40	13.70	42.20	17.40	1.45	3.24	50.20	1.48	0.00	2.07	0.82
Tågerup	TÅG 9	24670	32.50	18.50	46.20	16.30	1.20	3.67	36.20	1.83	0.52	1.68	2.12
Tågerup	TÅG 10	24186	16.80	10.20	24.20	18.80	1.30	3.46	43.10	-0.43	-0.49	0.24	-1.04
Tågerup	TÅG 11	10666	25.90	13.00	37.80	17.30	0.90	3.99	39.20	0.82	0.03	1.08	0.45
Tågerup	TÅG 12	10176	22.00	13.30	32.90	14.30	0.70	3.84	34.00	0.35	-0.45	0.86	-0.14
Tågerup	TÅG 13	14182	21.80	14.30	27.40	16.00	1.35	3.32	23.26	-0.07	-0.02	-0.54	0.34
Tågerup	TÅG 14	9240	16.90	13.30	25.60	13.60	1.10	2.95	35.30	-0.23	-0.87	0.61	-0.84
Tågerup	TÅG 15	16209	23.70	15.70	33.90	17.20	1.25	2.97	23.90	0.42	0.36	-0.12	0.98
Tågerup	TÅG 16	13396	20.50	15.30	33.50	17.50	0.65	2.21	40.70	0.48	-0.15	1.08	0.26
Tågerup	TÅG 17	11965	17.00	11.80	30.70	14.40	1.00	3.73	36.40	-0.05	-0.74	0.96	-0.95
Tågerup	TÅG 18	12503	17.20	12.40	32.90	13.90	1.10	3.52	34.70	0.08	-0.69	1.11	-0.80
Tågerup	TÅG 19	11511	22.60	15.00	33.80	16.40	0.70	3.11	45.50	0.68	-0.36	1.50	0.18
Tågerup	TÅG 20	14231	13.80	8.40	21.60	13.10	1.75	4.00	25.40	-1.01	-1.02	-0.42	-1.88
Tågerup	TÅG 21	11918	13.30	8.50	22.70	19.00	0.90	2.92	10.10	-1.30	0.20	-2.16	-0.91
Tågerup	TÅG 22	15385	19.00	13.60	29.10	16.80	1.20	3.23	25.00	-0.15	-0.02	-0.30	0.04
Tågerup	TÅG 23	18542	17.70	10.40	24.10	14.50	0.70	2.22	19.00	-0.70	-0.43	-0.91	-0.83
Tågerup	TÅG 24	7033	15.70	15.50	26.20	14.60	0.95	3.17	32.80	-0.20	-0.62	0.48	-0.40
Tågerup	TÅG 25	8034	15.60	11.70	28.50	13.90	1.10	3.87	45.00	-0.09	-1.11	1.49	-1.38
Tågerup	TÅG 26	12848	21.80	7.40	30.70	15.70	1.10	2.24	32.40	-0.13	-0.46	0.16	-1.04
Tågerup	TÅG 27	11348	18.70	8.50	28.10	14.90	0.75	2.62	31.50	-0.36	-0.65	0.14	-1.24
Tågerup	TÅG 28	11971	21.70	15.60	34.30	17.80	0.60	2.97	34.30	0.49	0.12	0.63	0.62
Tågerup	TÅG 29	19716	15.80	9.40	26.00	14.70	1.30	3.06	30.50	-0.58	-0.75	0.06	-1.39
Tågerup	TÅG 30	10606	17.10	9.70	24.30	15.10	0.70	2.10	23.80	-0.69	-0.51	-0.64	-1.05

Tab. 5.1

SITE 2	POINT ID	FIND NUMBER	EDGE	BASE	LONG DIAGONAL	SHORT DIAGONAL	WEIGHT	THICKNESS	ANGLE	PCA Comp. 1	PCA Comp. 2	DA Func. 1	DA Func. 2
Blak II	BLAK 1	1	21.00	15.30	27.40	23.50	N/A	N/A	15.00	-0.29	1.24	-2.06	1.42
Blak II	BLAK 2	2	17.10	12.70	21.20	21.10	N/A	N/A	11.00	-0.97	0.69	-2.49	0.34
Blak II	BLAK 3	3	22.20	16.20	34.90	19.90	N/A	N/A	24.00	0.38	0.73	-0.32	1.23
Blak II	BLAK 4	4	19.10	12.90	34.50	27.10	N/A	N/A	14.60	-0.23	1.75	-1.97	1.34
Blak II	BLAK 5	5	23.00	16.00	32.10	26.90	N/A	N/A	10.70	-0.04	1.99	-2.46	2.27
Blak II	BLAK 6	6	26.80	19.40	38.40	29.70	N/A	N/A	14.90	0.68	2.62	-2.02	3.52
Blak II	BLAK 7	7	21.90	13.00	30.30	24.30	N/A	N/A	6.80	-0.37	1.57	-2.61	1.43
Blak II	BLAK 8	8	22.70	17.70	34.50	25.90	N/A	N/A	11.10	0.18	1.94	-2.02	2.46
Blak II	BLAK 9	9	19.60	18.90	36.70	19.90	N/A	N/A	16.90	0.37	0.96	-0.46	1.65
Blak II	BLAK 10	10	29.50	22.40	30.90	27.60	N/A	N/A	3.10	0.45	2.67	-3.20	4.20
Blak II	BLAK 11	11	22.10	17.00	27.10	24.40	N/A	N/A	4.00	-0.35	1.73	-2.95	2.16
Blak II	BLAK 12	12	25.60	17.90	35.40	28.40	N/A	N/A	14.50	0.40	2.30	-2.14	2.97
Blak II	BLAK 13	13	23.80	14.20	41.90	29.00	N/A	N/A	19.90	0.50	2.20	-1.35	2.21
Blak II	BLAK 14	14	22.70	15.70	30.40	26.10	N/A	N/A	5.00	-0.23	1.98	-2.90	2.20
Blak II	BLAK 15	15	26.90	22.30	33.20	25.50	N/A	N/A	9.80	0.57	2.17	-2.15	3.61
Blak II	BLAK 16	16	25.10	17.00	32.60	20.10	N/A	N/A	20.00	0.39	0.92	-0.90	1.71
Blak II	BLAK 17	17	33.00	24.60	39.70	39.60	N/A	N/A	2.00	1.00	4.69	-4.17	6.35
Blak II	BLAK 18	18	34.20	16.30	29.50	22.80	N/A	N/A	8.50	0.44	1.77	-2.70	2.93
Blak II	BLAK 19	19	26.10	18.80	36.80	32.30	N/A	N/A	12.00	0.45	2.98	-2.70	3.66
Blak II	BLAK 20	20	22.50	18.40	38.40	23.70	N/A	N/A	8.20	0.38	1.81	-1.56	2.47
Blak II	BLAK 21	21	22.60	15.90	29.20	23.80	N/A	N/A	6.20	-0.24	1.61	-2.60	1.94
Blak II	BLAK 22	22	26.70	19.40	33.70	25.90	N/A	N/A	3.60	0.31	2.29	-2.70	3.28
Blak II	BLAK 23	23	26.00	20.90	30.90	24.30	N/A	N/A	5.90	0.28	1.99	-2.48	3.21
Blak II	BLAK 24	24	25.00	16.00	28.20	23.90	N/A	N/A	5.00	-0.18	1.71	-2.87	2.20
Blak II	BLAK 25	25	25.10	17.30	35.80	29.70	N/A	N/A	5.40	0.20	2.69	-2.92	3.17
Blak II	BLAK 26	26	22.70	20.60	33.10	25.30	N/A	N/A	12.30	0.30	1.90	-1.87	2.85
Blak II	BLAK 27	27	23.60	17.10	35.20	27.00	N/A	N/A	6.90	0.14	2.22	-2.46	2.66
Blak II	BLAK 28	28	34.00	18.00	40.10	35.20	N/A	N/A	2.20	0.77	3.90	-3.82	4.84
Blak II	BLAK 29	29	26.50	18.10	32.30	25.50	N/A	N/A	9.30	0.26	2.01	-2.41	2.84
Blak II	BLAK 30	30	35.20	28.10	27.00	15.10	N/A	N/A	12.70	1.20	0.98	-1.19	4.11

Tab. 5.2

SITE 3	POINT ID	FIND NUMBER	EDGE	BASE	LONG DIAGONAL	SHORT DIAGONAL	WEIGHT	THICKNESS	ANGLE	PCA Comp. 1	PCA Comp. 2	DA Func. 1	DA Func. 2
Kongemose	KONG 1	43-10:2	17.20	9.40	30.40	17.30	1.05	3.02	29.55	0.11	0.37	-0.03	-0.89
Kongemose	KONG 2	39,0/39,5-26:S 901	19.60	19.40	30.10	14.60	0.52	2.22	39.79	-0.60	-1.19	1.30	0.54
Kongemose	KONG 3	31-16:24	24.50	16.60	36.30	14.30	0.99	3.61	46.57	-0.05	0.34	2.06	0.43
Kongemose	KONG 4	45-16:9	22.80	19.20	32.70	14.60	0.70	2.71	47.38	0.33	-0.97	1.93	0.68
Kongemose	KONG 5	27-16:1	21.40	13.60	36.60	18.20	1.06	2.56	38.67	-1.27	-0.78	1.02	0.22
Kongemose	KONG 6	31-12:7	16.70	12.70	27.20	13.20	0.74	2.80	37.62	0.22	-0.29	0.95	-1.03
Kongemose	KONG 7	31-18:9	19.40	9.00	27.40	14.20	0.78	3.33	35.96	0.55	-0.48	0.48	-1.28
Kongemose	KONG 8	25-27:1	9.80	9.60	26.80	16.20	0.65	2.74	18.16	-0.35	-0.78	-0.70	-1.46
Kongemose	KONG 9	38,5/39,5-25,5/26:	22.00	12.40	34.10	15.70	1.66	3.19	39.06	-0.20	0.35	1.10	-0.24
Kongemose	KONG 10	38,0/38,5-26:S 758	27.70	16.80	37.50	14.60	1.17	3.61	47.20	1.40	1.04	2.05	0.80
Kongemose	KONG 11	34-16:5	17.60	6.80	30.50	17.30	1.05	3.49	34.73	0.37	-0.44	0.23	-1.42
Kongemose	KONG 12	43-17:5	19.50	12.80	26.20	14.60	0.63	2.45	32.02	0.71	-1.09	0.19	-0.50
Kongemose	KONG 13	38-29:S 733	28.40	14.70	39.30	13.10	1.14	2.82	57.81	1.11	-0.74	3.04	0.13
Kongemose	KONG 14	25-18:1	26.60	6.20	41.00	15.60	1.58	3.28	59.92	0.45	-1.05	2.76	-1.26
Kongemose	KONG 15	36-16:17	21.80	9.20	28.40	11.90	0.68	3.30	50.20	-0.01	-1.28	1.79	-1.57
Kongemose	KONG 16	46-16:2	31.10	19.70	42.70	17.50	1.36	3.14	45.92	-0.85	-0.64	2.00	2.04
Kongemose	KONG 17	40-28,0/28,5:1	19.90	5.20	29.30	13.50	0.83	3.05	45.15	-0.60	0.13	1.22	-2.14
Kongemose	KONG 18	43-21:4	25.70	15.00	35.80	15.70	1.13	3.07	47.04	1.02	-0.34	1.76	0.40
Kongemose	KONG 19	42-16:7	18.30	19.50	35.40	16.30	1.20	3.42	38.74	-0.35	-1.17	1.51	0.74
Kongemose	KONG 20	36-27:S 19515	21.60	8.80	34.20	16.20	0.71	2.49	43.18	-0.39	-0.91	1.21	-0.94
Kongemose	KONG 21	35-28,0/28,5:1	20.30	15.00	35.10	16.90	0.70	2.46	38.97	0.02	-1.98	1.18	0.20
Kongemose	KONG 22	38,0/38,5-15:S 865	22.30	10.90	31.70	14.60	0.99	3.07	45.22	1.14	0.12	1.40	-0.78
Kongemose	KONG 23	35-16:14	20.50	15.10	32.90	15.20	1.13	3.47	43.61	0.57	-0.31	1.54	-0.09
Kongemose	KONG 24	29-16:16	14.20	13.30	32.40	20.50	0.66	3.18	29.83	0.76	-1.16	-0.01	-0.12
Kongemose	KONG 25	31-14:344	18.00	15.90	29.80	12.60	0.53	2.71	39.07	0.17	-0.79	1.43	-0.41
Kongemose	KONG 26	31-14:570	19.00	9.00	31.70	15.40	1.04	3.62	46.59	-0.08	-0.46	1.45	-1.36
Kongemose	KONG 27	36-29,5/30:2	21.40	12.00	33.60	17.90	1.52	3.72	36.53	0.66	0.59	0.59	-0.09
Kongemose	KONG 28	45-16:1	26.50	14.80	44.10	16.10	1.24	2.97	52.52	-0.19	-1.15	2.76	0.50
Kongemose	KONG 29	38,0/38,5-25:S 762	32.90	14.70	38.50	17.60	1.32	2.81	42.10	-0.63	-1.15	1.11	1.37
Kongemose	KONG 30	35-16:21	12.70	2.50	22.50	14.00	0.40	2.25	37.99	-0.27	-0.97	0.24	-3.18

Tab. 5.3

SITE 4	POINT ID	FIND NUMBER	EDGE	BASE	LONG DIAGONAL	SHORT DIAGONAL	WEIGHT	THICKNESS	ANGLE	PCA Comp. 1	PCA Comp. 2	DA Func. 1	DA Func. 2
Månedale	MÅNE 1	M6 700	26.50	12.70	33.80	12.10	0.90	3.25	48.40	0.86	-1.00	2.05	-0.38
Månedale	MÅNE 2	M6 741	39.70	18.30	33.50	13.10	2.15	4.52	47.40	1.79	-0.27	1.53	1.94
Månedale	MÅNE 3	M6 280	26.70	18.20	35.40	15.80	1.15	2.69	28.70	0.88	0.25	0.51	1.46
Månedale	MÅNE 4	M6 708	35.20	23.30	27.40	17.50	1.05	2.92	44.90	1.44	0.32	0.60	2.80
Månedale	MÅNE 5	M6 556	43.80	20.80	44.20	17.50	1.65	3.94	49.50	2.64	0.70	1.94	3.35
Månedale	MÅNE 6	M6 915	29.10	13.50	36.10	17.20	1.30	3.98	17.00	0.57	0.67	-0.70	1.30
Månedale	MÅNE 7	M6 971	23.80	13.30	33.50	13.10	0.90	2.77	39.80	0.58	-0.70	1.41	-0.22
Månedale	MÅNE 8	M6 725	22.30	18.60	34.70	14.30	1.15	3.86	40.20	0.85	-0.38	1.63	0.69
Månedale	MÅNE 9	M6 343	21.90	12.80	30.00	16.90	0.95	3.01	32.50	0.12	-0.13	0.15	0.02
Månedale	MÅNE 10	M6 375	29.10	8.60	32.20	12.70	0.90	2.47	54.00	0.77	-1.15	1.97	-0.94
Månedale	MÅNE 11	M6 133	24.70	14.00	33.90	12.40	0.80	2.73	45.60	0.79	-0.89	1.94	-0.22
Månedale	MÅNE 12	M6 39	21.90	14.70	35.20	13.70	0.85	2.90	41.70	0.67	-0.64	1.73	-0.11
Månedale	MÅNE 13	M6 1045	23.50	15.30	34.00	14.60	1.20	3.33	32.80	0.57	-0.24	0.85	0.42
Månedale	MÅNE 14	M6 557	28.70	16.00	39.90	15.50	1.30	3.21	47.60	1.39	-0.21	2.10	0.88
Månedale	MÅNE 15	M6 905	25.40	20.90	38.40	16.90	1.40	2.78	41.10	1.29	0.19	1.63	1.70
Månedale	MÅNE 16	M6 837	33.40	20.80	41.40	16.60	2.00	4.48	53.10	2.04	0.13	2.46	2.17
Månedale	MÅNE 17	M6 571	36.30	36.30	39.80	14.90	1.90	4.57	52.80	2.98	0.48	3.00	4.92
Månedale	MÅNE 18	M6 31	26.70	18.10	37.40	14.80	1.50	3.90	36.70	1.11	-0.06	1.37	1.19
Månedale	MÅNE 19	M6 667	34.30	15.20	35.70	20.80	1.45	3.38	53.40	1.44	0.42	1.20	1.62
Månedale	MÅNE 20	M6 447	19.80	14.50	32.30	18.70	2.15	4.59	12.30	-0.13	0.68	-1.17	0.81
Månedale	MÅNE 21	M6 205	19.10	16.30	32.60	21.70	1.70	3.78	46.70	0.46	0.25	0.96	0.60
Månedale	MÅNE 22	M6 526	26.90	12.00	36.30	13.90	1.05	3.63	45.80	0.89	-0.64	1.80	-0.17
Månedale	MÅNE 23	M6 57	22.30	7.40	36.80	18.90	1.65	3.62	37.60	0.23	-0.02	0.60	-0.66
Månedale	MÅNE 24	M6 859	32.80	10.20	40.70	13.30	1.50	3.93	35.70	1.16	-0.27	1.26	0.31
Månedale	MÅNE 25	M6 709	27.50	18.40	37.60	16.10	1.60	3.23	30.70	1.07	0.31	0.77	1.60
Månedale	MÅNE 26	M6 1044	24.10	13.70	36.80	20.10	0.90	2.79	53.50	0.91	0.00	1.72	0.36
Månedale	MÅNE 27	M6 1038	18.60	8.10	26.80	16.80	0.70	2.66	42.50	-0.30	-0.72	0.54	-1.39
Månedale	MÅNE 28	M6 263	23.50	15.20	32.80	18.30	2.20	3.80	25.20	0.33	0.44	-0.28	0.95
Månedale	MÅNE 29	M6 242	26.70	15.60	39.30	13.20	1.40	4.15	43.70	1.20	-0.51	2.14	0.46
Månedale	MÅNE 30	M6 838	28.30	14.10	36.70	15.30	2.70	4.95	39.70	0.98	-0.17	1.24	0.62

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SITE 5	POINT ID	FIND NUMBER	EDGE	BASE	LONG DIAGONAL	SHORT DIAGONAL	WEIGHT	THICKNESS	ANGLE	PCA Comp. 1	PCA Comp. 2	DA Func. 1	DA Func. 2
Stationsvej 19	STA 1	23254001.00	15.30	15.30	28.90	11.50	0.80	3.14	48.80	0.20	-1.42	2.26	-1.12
Stationsvej 19	STA 2	24263007.00	19.10	10.80	26.80	11.20	0.60	2.48	39.80	-0.09	-1.31	1.18	-1.41
Stationsvej 19	STA 3	24254002.00	19.60	15.90	27.80	16.80	1.20	3.84	30.20	0.03	-0.09	0.01	0.35
Stationsvej 19	STA 4	5043295.00	29.00	12.70	40.50	14.40	1.45	3.88	45.20	1.23	-0.39	1.99	0.29
Stationsvej 19	STA 5	24251001.00	21.80	8.60	30.70	17.30	1.35	3.68	34.20	-0.06	-0.25	0.12	-0.70
Stationsvej 19	STA 6	24262002.00	19.70	17.20	37.20	14.10	0.65	2.14	30.40	0.61	-0.23	1.23	0.46
Stationsvej 19	STA 7	24263006.00	25.60	19.90	40.40	16.20	2.10	4.36	32.70	1.22	0.33	1.26	1.69
Stationsvej 19	STA 8	24251001.00	20.00	11.90	32.80	16.30	1.35	3.68	31.10	0.09	-0.20	0.41	-0.29
Stationsvej 19	STA 9	24282002.00	24.10	17.30	35.30	12.90	1.15	3.28	49.00	1.06	-0.78	2.37	0.30
Stationsvej 19	STA 10	23313001.00	15.80	15.80	26.50	14.10	1.00	3.96	39.80	-0.04	-0.85	1.07	-0.55
Stationsvej 19	STA 11	5045591.00	18.20	14.60	28.90	15.90	0.85	2.58	32.50	-0.01	-0.33	0.39	-0.13
Stationsvej 19	STA 12	24261002.00	13.00	19.90	25.40	14.90	1.00	3.24	35.10	-0.10	-0.58	0.80	0.08
Stationsvej 19	STA 13	25272001.00	13.60	7.40	25.30	21.10	1.40	3.56	3.30	-1.36	0.69	-2.75	-0.65
Stationsvej 19	STA 14	22301002.00	23.90	17.20	35.40	15.20	1.05	2.87	46.70	0.98	-0.42	1.92	0.56
Stationsvej 19	STA 15	23261005.00	29.10	9.00	30.60	14.20	1.25	2.98	43.30	0.52	-0.69	0.90	-0.49
Stationsvej 19	STA 16	21371327.00	17.60	13.00	29.10	13.30	0.70	2.64	42.00	0.07	-1.01	1.38	-0.96
Stationsvej 19	STA 17	23232001.00	18.30	13.50	26.90	14.30	0.80	2.65	40.30	-0.02	-0.83	0.94	-0.70
Stationsvej 19	STA 18	24282001.00	28.50	16.60	32.00	16.50	1.20	3.39	51.70	1.08	-0.32	1.61	0.84
Stationsvej 19	STA 19	24262001.00	21.20	14.80	28.10	14.20	1.25	3.43	33.70	0.16	-0.52	0.53	-0.04
Stationsvej 19	STA 20	23243003.00	23.60	15.90	34.90	13.30	1.30	4.14	47.40	0.91	-0.76	2.14	0.08
Stationsvej 19	STA 21	23294001.00	22.30	15.90	35.50	14.00	1.00	2.86	44.00	0.80	-0.60	1.91	0.12
Stationsvej 19	STA 22	24224001.00	18.30	15.40	32.70	15.20	1.35	4.16	31.00	0.21	-0.29	0.73	0.04
Stationsvej 19	STA 23	22294002.00	14.00	12.80	29.70	17.00	0.90	3.09	25.10	-0.42	-0.16	-0.11	-0.54
Stationsvej 19	STA 24	23294001.00	23.00	20.20	35.90	17.50	1.00	2.86	49.70	1.14	-0.09	2.01	1.18
Stationsvej 19	STA 25	24252001.00	18.10	16.70	36.30	15.60	1.10	4.13	29.60	-0.21	-0.49	0.94	0.38
Stationsvej 19	STA 26	25252001.00	18.40	15.00	32.10	17.90	1.30	3.72	30.10	0.11	0.09	0.24	0.28
Stationsvej 19	STA 27	24272001.00	22.10	16.50	37.00	15.60	1.60	3.66	42.60	0.86	-0.30	1.75	0.43
Stationsvej 19	STA 28	5044373.00	18.90	12.70	29.50	13.60	1.05	3.24	37.90	0.07	-0.82	1.03	-0.75
Stationsvej 19	STA 29	22302002.00	24.80	18.30	36.70	14.90	0.90	3.15	55.10	1.29	-0.59	2.66	0.63
Stationsvej 19	STA 30	23292002.00	14.00	12.80	29.70	17.60	0.90	3.09	25.00	-0.43	-0.07	-0.20	-0.47

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SITE 6	POINT ID	FIND NUMBER	EDGE	BASE	LONG DIAGONAL	SHORT DIAGONAL	WEIGHT	THICKNESS	ANGLE	PCA Comp. 1	PCA Comp. 2	DA Func. 1	DA Func. 2
Segebro	SEG 1	X22Y2.5BR2	18.00	14.50	33.40	14.70	1.25	3.57	51.50	0.52	-0.91	2.27	-0.65
Segebro	SEG 2	X29Y0-0.5SUL	13.30	12.40	24.70	13.20	0.40	1.90	31.70	-0.56	-0.98	0.44	-1.31
Segebro	SEG 3	X22Y2G5	19.90	18.20	36.00	14.70	1.80	4.20	58.80	1.06	-0.87	3.07	0.04
Segebro	SEG 4	X22Y7BRL1	22.90	13.50	30.70	10.77	1.50	4.48	52.40	0.65	-1.43	2.41	-0.86
Segebro	SEG 5	X48Y0BRL	28.00	13.00	28.50	19.50	0.95	3.02	48.50	0.59	-0.03	0.57	0.50
Segebro	SEG 6	X31-Y2SUL	15.10	14.50	27.80	13.20	0.95	3.02	48.50	0.07	-1.23	1.89	-1.11
Segebro	SEG 7	X26Y99UL	24.80	20.80	41.80	15.60	1.50	1.95	60.00	1.74	-0.43	3.44	1.12
Segebro	SEG 8	X24Y9SV2	22.60	15.30	35.80	11.70	0.80	2.87	38.50	0.75	-0.78	1.82	-0.07
Segebro	SEG 9	X31Y10POR	17.20	11.20	29.20	16.40	1.20	3.46	36.70	-0.17	-0.51	0.56	-0.85
Segebro	SEG 10	X23Y11GY183	26.80	17.20	24.50	24.40	1.45	3.50	44.70	0.43	0.77	-0.49	1.66
Segebro	SEG 11	X31Y14GY182	15.50	8.10	30.80	17.30	1.75	4.37	48.00	-0.18	-0.81	1.31	-1.68
Segebro	SEG 12	X43Y8GS174	10.90	8.10	28.40	28.00	1.15	3.53	53.00	-0.61	0.35	0.21	-1.13
Segebro	SEG 13	X47Y0TAR1179	27.20	12.90	30.20	15.30	1.10	2.77	40.40	0.55	-0.39	0.73	0.18
Segebro	SEG 14	X30Y8BR1	20.10	8.90	32.20	13.70	0.90	3.02	32.80	-0.03	-0.72	0.71	-1.13
Segebro	SEG 15	X20Y6BR1	16.80	11.20	34.10	15.60	1.25	3.59	29.00	-0.07	-0.34	0.56	-0.71
Segebro	SEG 16	X30Y10BRL	24.20	16.00	37.10	14.40	1.35	3.85	46.80	1.02	-0.53	2.12	0.32
Segebro	SEG 17	X26Y22-22.5	27.40	18.60	36.40	15.30	1.00	2.46	29.00	1.00	0.23	0.67	1.56
Segebro	SEG 18	X80Y-10	22.50	21.80	32.50	17.60	1.35	3.58	43.50	0.93	0.05	1.35	1.50
Segebro	SEG 19	X28Y9SUL	22.60	14.80	35.50	12.70	1.05	2.92	38.70	0.69	-0.67	1.66	-0.06
Segebro	SEG 20	X7Y112-11	25.50	14.70	41.10	14.20	1.00	3.17	33.40	1.00	-0.13	1.45	0.57
Segebro	SEG 21	X02-32.5Y7SVL	14.70	14.50	25.80	13.90	1.15	3.74	41.30	-0.18	-1.00	1.14	-0.94
Segebro	SEG 22	X7Y11.2-11.6	15.10	15.70	26.00	14.40	1.65	3.57	37.90	-0.14	-0.79	0.88	-0.56
Segebro	SEG 23	X27.5-28Y6SVL	14.50	11.50	35.80	23.60	1.20	3.03	54.30	0.21	0.08	1.51	-0.58
Segebro	SEG 24	X35-40	18.40	10.50	30.20	20.00	1.30	3.60	32.80	-0.22	0.11	-0.18	-0.38
Segebro	SEG 25	X46Y0	14.50	13.50	28.70	16.70	1.40	2.65	35.70	-0.23	-0.46	0.59	-0.66
Segebro	SEG 26	X26Y11.5-12	14.20	13.80	30.80	14.70	1.65	3.84	44.00	0.04	-0.90	1.64	-1.00
Segebro	SEG 27	X21,5-22Y2	16.60	13.60	27.80	12.20	1.95	3.96	32.70	-0.15	-0.95	0.83	-0.87
Segebro	SEG 28	X21Y-.05-1	17.20	17.60	30.80	15.00	1.00	2.89	35.20	0.25	-0.42	1.01	0.17
Segebro	SEG 29	X30Y4-4.58VL	15.30	11.70	28.70	19.30	1.05	3.99	48.70	-0.12	-0.47	1.06	-0.92
Segebro	SEG 30	X27.5Y6SUL(67)	20.50	13.00	32.10	14.20	1.00	2.95	49.40	0.47	-0.93	1.93	-0.71

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SITE 7	POINT ID	FIND NUMBER	EDGE	BASE	LONG DIAGONAL	SHORT DIAGONAL	WEIGHT	THICKNESS	ANGLE	PCA Comp. 1	PCA Comp. 2	DA Func. 1	DA Func. 2
Villingebæk Øst A	VILL 1	211	18.70	16.00	31.00	14.20	1.25	2.95	29.00	0.16	-0.37	0.59	0.09
Villingebæk Øst A	VILL 2	1952	26.20	15.00	43.10	15.00	1.95	4.13	44.80	1.32	-0.25	2.30	0.55
Villingebæk Øst A	VILL 3	729	25.00	14.80	39.20	17.40	1.10	2.58	41.70	0.98	0.04	1.47	0.66
Villingebæk Øst A	VILL 4	304	19.20	17.50	35.60	14.70	1.05	2.98	47.30	0.78	-0.62	2.23	0.11
Villingebæk Øst A	VILL 5	2546	18.30	6.70	25.50	20.20	1.00	3.10	20.00	-0.87	0.25	-1.64	-0.81
Villingebæk Øst A	VILL 6	2405	17.60	16.20	29.30	13.30	0.60	2.45	51.00	0.40	-1.13	2.15	-0.60
Villingebæk Øst A	VILL 7	3046	25.90	19.50	41.60	18.80	1.95	3.25	32.90	1.24	0.70	1.01	1.94
Villingebæk Øst A	VILL 8	401	18.90	12.60	36.40	15.70	1.00	3.92	53.20	0.62	-0.80	2.41	-0.78
Villingebæk Øst A	VILL 9	1797	28.80	7.30	40.30	16.20	1.90	3.16	45.30	0.89	-0.34	1.55	-0.48
Villingebæk Øst A	VILL 10	1845	17.80	15.90	34.50	13.70	1.15	3.03	53.90	0.69	-1.05	2.73	-0.57
Villingebæk Øst A	VILL 11	2520	17.30	13.00	28.40	17.60	1.55	4.16	29.50	-0.24	-0.11	-0.11	-0.26
Villingebæk Øst A	VILL 12	4288	22.00	15.90	41.70	14.20	1.20	2.83	44.50	1.10	-0.47	2.46	0.21
Villingebæk Øst A	VILL 13	3651	33.00	24.40	38.80	17.30	0.80	2.52	55.00	2.11	0.23	2.43	2.74
Villingebæk Øst A	VILL 14	3526	33.40	6.50	35.40	14.00	1.30	3.34	67.50	1.23	-1.21	2.78	-1.02
Villingebæk Øst A	VILL 15	90	27.50	15.70	40.30	15.10	1.60	2.97	46.10	1.31	-0.26	2.11	0.72
Villingebæk Øst A	VILL 16	2722	30.40	18.20	50.00	15.40	1.65	3.03	63.20	2.34	-0.30	4.08	1.23
Villingebæk Øst A	VILL 17	2251	23.70	22.60	52.50	23.40	3.10	4.60	46.80	1.99	1.23	2.50	2.64
Villingebæk Øst A	VILL 18	460	22.10	12.80	30.40	17.00	1.05	3.03	29.70	0.10	-0.03	-0.04	0.12
Villingebæk Øst A	VILL 19	2529	27.60	12.20	46.70	20.70	3.25	4.99	51.00	1.44	0.39	2.12	0.71
Villingebæk Øst A	VILL 20	137	18.40	9.70	28.70	15.80	0.80	2.51	41.90	-0.13	-0.76	0.86	-1.19
Villingebæk Øst A	VILL 21	3588	22.60	13.60	32.20	16.20	1.30	3.77	49.40	0.59	-0.57	1.61	-0.20
Villingebæk Øst A	VILL 22	2447	24.40	7.40	36.50	14.70	1.50	3.62	43.50	0.48	-0.70	1.47	-1.05
Villingebæk Øst A	VILL 23	1798	16.10	5.30	30.20	13.80	1.05	3.21	38.70	-0.44	-1.13	0.95	-2.28
Villingebæk Øst A	VILL 24	4427	21.60	11.30	26.70	18.10	1.35	3.82	24.20	-0.29	0.13	-0.92	-0.01
Villingebæk Øst A	VILL 25	2366	21.60	9.80	34.10	17.00	1.80	3.64	46.00	0.35	-0.49	1.33	-0.75
Villingebæk Øst A	VILL 26	2419	29.00	16.50	39.80	15.80	1.55	3.53	48.90	1.44	-0.18	2.15	1.00
Villingebæk Øst A	VILL 27	1960	40.20	13.10	26.80	15.40	1.40	3.24	51.30	1.24	-0.35	0.71	1.12
Villingebæk Øst A	VILL 28	969	17.50	12.30	42.70	18.20	2.30	4.21	34.50	0.50	0.11	1.34	-0.16
Villingebæk Øst A	VILL 29	2351	24.90	8.90	36.40	16.90	1.55	3.57	39.40	0.48	-0.23	0.92	-0.42
Villingebæk Øst A	VILL 30	1405	22.40	13.70	37.10	13.20	1.45	4.02	44.00	0.78	-0.75	2.07	-0.31

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SITE 8	POINT ID	FIND NUMBER	EDGE	BASE	LONG DIAGONAL	SHORT DIAGONAL	WEIGHT	THICKNESS	ANGLE	PCA 1	PCA 2	DA 1	DA 2
SU7	SU7 1	20R3011/246	12.30	11.40	26.60	21.40	0.60	2.70	12.60	-1.00	0.61	-1.83	-0.24
SU7	SU7 2	20R3018/140	12.70	4.30	18.00	14.30	1.25	2.62	4.70	-1.82	-0.56	-2.44	-2.15
SU7	SU7 3	20R3002/27	13.00	3.30	19.50	19.20	0.70	3.12	8.30	-1.79	0.02	-2.77	-1.84
SU7	SU7 4	20R3011/896	17.00	4.80	26.10	25.70	1.55	4.88	2.80	-1.36	1.36	-3.55	-0.28
SU7	SU7 5	20R3002/923	12.90	7.90	20.40	20.40	0.65	3.28	0.90	-1.64	0.55	-3.19	-0.74
SU7	SU7 6	20R3007/927	16.10	10.70	23.10	22.80	1.60	5.86	3.60	-1.18	1.05	-3.11	0.28
SU7	SU7 7	20R3016/305	15.20	6.50	30.70	30.20	1.70	3.71	13.00	-1.05	1.81	-2.91	0.17
SU7	SU7 8	22R3051/698	18.00	6.70	30.90	29.30	2.30	4.58	10.30	-0.90	1.85	-3.06	0.44
SU7	SU7 9	20R3024/211	19.10	7.60	26.70	18.60	0.80	2.66	26.00	-0.60	-0.05	-0.90	-0.87
SU7	SU7 10	20R3038/610	16.80	7.50	21.30	13.90	1.70	5.48	34.00	-0.79	-1.08	-0.09	-1.87
SU7	SU7 11	20R3009/499	14.50	3.30	32.00	28.00	0.80	2.90	10.90	-1.19	1.46	-2.75	-0.61
SU7	SU7 12	20R3008/342	10.60	6.60	26.70	27.00	1.35	4.47	10.10	-1.46	1.24	-2.85	-0.58
SU7	SU7 13	20R3038/609	21.30	10.10	26.50	23.50	0.80	3.00	1.90	-0.82	1.39	-3.25	0.83
SU7	SU7 14	22R3051/701	12.50	10.10	22.30	17.68	1.35	4.07	29.20	-0.96	-0.44	-0.59	-1.29
SU7	SU7 15	22R3052/925	18.80	7.30	24.70	21.80	0.70	2.75	0.70	-1.18	0.99	-3.27	-0.07
SU7	SU7 16	20R3008/342	14.10	8.50	20.10	15.80	1.35	4.47	14.30	-1.28	-0.38	-1.69	-1.32
SU7	SU7 17	20R3008/341	19.80	6.30	19.00	17.80	1.65	3.17	0.90	-1.41	0.31	-3.29	-0.68
SU7	SU7 18	22R3054/853	12.70	4.40	21.20	19.50	1.67	5.74	6.80	-1.69	0.17	-2.71	-1.58
SU7	SU7 19	20R3009/499	13.20	10.60	23.70	21.20	0.80	2.90	7.70	-1.22	0.65	-2.45	-0.25
SU7	SU7 20	22R3055/789	16.60	4.20	29.40	29.80	3.55	6.04	2.40	-1.32	1.97	-3.85	0.08
SU7	SU7 21	223052/665	12.40	3.10	24.60	25.00	0.95	2.79	3.10	-1.75	1.03	-3.45	-1.11
SU7	SU7 22	1231/921	14.90	7.90	23.40	19.00	1.10	4.52	12.90	-1.18	0.17	-1.99	-0.92
SU7	SU7 23	21R3034/91	18.50	5.40	23.90	13.50	2.40	5.05	38.30	-0.62	-1.22	0.34	-2.17
SU7	SU7 24	20R3021/477	19.40	3.90	34.50	23.90	1.10	5.47	32.10	-0.38	0.56	-0.67	-0.93
SU7	SU7 25	20R3011/896	15.60	7.60	18.20	22.90	1.55	4.88	6.90	-1.56	0.76	-3.41	-0.45
SU7	SU7 26	20R3021/475	17.30	7.90	23.20	12.60	3.30	4.20	35.20	-0.61	-1.22	0.32	-1.89
SU7	SU7 27	20R30222/341	13.90	8.60	21.10	19.20	1.40	4.25	14.80	-1.27	0.09	-2.01	-0.96
SU7	SU7 28	20R3012/425	20.20	3.10	24.70	15.60	0.65	3.26	28.80	-0.80	-0.70	-0.69	-1.96
SU7	SU7 29	1231/922	14.20	2.70	18.50	22.80	0.90	3.24	16.40	-1.74	0.30	-2.83	-1.65
SU7	SU7 30	20R3011/896	15.20	2.50	28.90	30.04	1.55	4.88	0.10	-1.55	1.95	-4.10	-0.28

Tab. 5.8

SITE 9	POINT ID	FIND NUMBER	EDGE	BASE	LONG DIAGONAL	SHORT DIAGONAL	WEIGHT	THICKNESS	ANGLE	PCA Comp. 1	PCA Comp. 2	DA Func. 1	DA Func. 2
Tågerup Ertebølle	TÅG ERT 1	19558	13.20	4.60	18.40	17.90	0.70	3.75	1.10	-1.86	0.06	-3.15	-1.59
Tågerup Ertebølle	TÅG ERT 2	18326	12.30	0.56	18.90	19.80	0.50	3.85	13.60	-1.93	-0.16	-2.60	-2.44
Tågerup Ertebølle	TÅG ERT 3	18326	13.80	3.90	19.00	14.20	0.50	3.18	17.60	-1.52	-0.87	-1.50	-2.41
Tågerup Ertebølle	TÅG ERT 4	18326	18.00	6.80	20.40	14.20	0.60	2.68	6.40	-1.26	-0.33	-2.22	-1.24
Tågerup Ertebølle	TÅG ERT 5	19559	16.60	2.60	21.00	17.90	0.45	3.11	16.70	-1.42	-0.26	-2.04	-1.93
Tågerup Ertebølle	TÅG ERT 6	19559	11.20	3.90	16.90	15.90	0.40	2.48	2.30	-2.03	-0.36	-2.88	-2.16
Tågerup Ertebølle	TÅG ERT 7	19639	13.80	8.40	31.40	24.40	1.50	3.79	21.60	-0.75	0.83	-1.35	-0.42
Tågerup Ertebølle	TÅG ERT 8	18324	10.80	3.80	20.10	18.00	0.55	2.92	1.90	-1.94	-0.01	-2.90	-1.92
Tågerup Ertebølle	TÅG ERT 9	18320	14.40	7.30	22.10	20.30	0.70	2.27	4.00	-1.46	0.52	-2.90	-0.75
Tågerup Ertebølle	TÅG ERT 10	18326	14.00	3.60	27.70	18.90	0.65	2.26	29.70	-0.98	-0.37	-0.55	-2.07
Tågerup Ertebølle	TÅG ERT 11	18324	11.50	3.90	21.00	20.80	0.65	2.92	4.20	-1.85	0.36	-3.06	-1.58
Tågerup Ertebølle	TÅG ERT 12	14689	12.80	3.80	15.10	14.00	0.40	2.73	6.80	-1.94	-0.73	-2.53	-2.36
Tågerup Ertebølle	TÅG ERT 13	14689	10.80	4.90	20.04	19.30	0.35	2.35	11.80	-1.74	-0.05	-2.35	-1.82
Tågerup Ertebølle	TÅG ERT 14	14357	10.20	4.00	17.00	16.10	0.35	3.03	13.10	-1.90	-0.63	-2.10	-2.45
Tågerup Ertebølle	TÅG ERT 15	14357	13.80	10.20	21.30	19.50	0.55	1.96	4.30	-1.35	0.46	-2.71	-0.41
Tågerup Ertebølle	TÅG ERT 16	14357	8.40	5.90	15.00	13.10	0.33	2.32	13.40	-1.94	-1.08	-1.71	-2.65
Tågerup Ertebølle	TÅG ERT 17	16871	10.90	3.60	23.80	21.30	0.60	2.74	17.70	-1.55	0.10	-1.93	-1.90
Tågerup Ertebølle	TÅG ERT 18	16896	12.50	3.70	23.80	23.10	1.05	4.18	10.30	-1.61	0.59	-2.75	-1.37
Tågerup Ertebølle	TÅG ERT 19	18326	8.40	2.60	16.20	15.30	0.25	2.27	6.80	-2.20	-0.69	-2.49	-2.82
Tågerup Ertebølle	TÅG ERT 20	18324	11.60	4.10	18.60	19.20	0.60	2.93	2.70	-1.96	0.14	-3.15	-1.72
Tågerup Ertebølle	TÅG ERT 21	19558	8.80	8.20	18.30	16.10	0.45	1.66	23.60	-1.51	-0.78	-1.04	-2.07
Tågerup Ertebølle	TÅG ERT 22	18326	9.80	4.00	18.00	12.80	0.30	4.09	14.70	-1.80	-1.12	-1.45	-2.86
Tågerup Ertebølle	TÅG ERT 23	20117	17.50	5.30	24.00	22.50	1.20	3.03	8.50	-1.28	0.76	-2.90	-0.65
Tågerup Ertebølle	TÅG ERT 24	14690	9.50	5.10	19.60	18.30	0.40	3.26	3.50	-1.93	-0.01	-2.78	-1.83
Tågerup Ertebølle	TÅG ERT 25	15314	10.70	4.80	20.60	15.20	0.40	2.14	30.60	-1.36	-1.10	-0.44	-2.70
Tågerup Ertebølle	TÅG ERT 26	20117	9.90	8.30	14.80	12.60	0.25	2.47	11.50	-1.76	-0.98	-1.76	-2.11
Tågerup Ertebølle	TÅG ERT 27	14690	15.50	2.30	21.70	19.10	0.70	2.12	5.90	-1.65	0.16	-2.87	-1.70
Tågerup Ertebølle	TÅG ERT 28	15314	15.70	2.70	26.20	23.40	0.90	3.57	10.10	-1.39	0.75	-2.75	-1.17
Tågerup Ertebølle	TÅG ERT 29	20117	11.60	3.50	25.50	24.00	0.95	2.42	0.20	-1.76	0.98	-3.40	-1.13
Tågerup Ertebølle	TÅG ERT 30	25146	11.40	5.70	20.07	11.70	0.35	1.66	28.40	-1.29	-1.48	-0.16	-2.81

Tab. 5.9

SITE	STAT	EDGE	BASE	LONG DIAGONAL	SHORT DIAGONAL	WEIGHT	THICKNESS	ANGLE
TÅG	CV	23.35	24.04	19.40	13.42	29.06	19.77	28.86
BLAK	CV	17.71	18.16	12.59	19.05	N/A	N/A	52.29
KONG	CV	23.98	35.05	15.30	12.14	33.85	14.05	20.40
MÅNE	CV	22.11	34.19	10.93	16.13	35.37	19.49	25.75
ST19	CV	21.96	27.52	13.60	13.38	27.82	16.91	27.80
SEG	CV	25.07	23.73	14.06	23.95	26.79	19.21	20.85
VILL	CV	24.09	34.18	18.79	14.40	40.37	18.52	24.49
SU7	CV	18.08	40.67	17.90	24.12	52.19	27.09	90.27
TÅG ERT	CV	21.04	44.50	18.70	20.12	49.49	24.43	75.88

Tab. 5.10 Coefficient of variation.

SITE	STAT	EDGE	BASE	LONG DIAGONAL	SHORT DIAGONAL	WEIGHT	THICKNESS	ANGLE
TÅG	MEAN	20.62	12.39	30.55	15.71	1.05	3.20	34.60
BLAK	MEAN	25.08	17.94	33.05	25.78	N/A	N/A	10.05
KONG	MEAN	21.31	12.66	33.14	15.51	0.97	3.02	41.57
MÅNE	MEAN	27.42	15.90	35.51	15.89	1.40	3.53	40.69
ST19	MEAN	20.36	14.79	31.95	15.22	1.12	3.33	37.58
SEG	MEAN	19.46	14.02	31.52	16.12	1.23	3.31	42.29
VILL	MEAN	23.74	13.48	36.40	16.30	1.48	3.41	43.81
SU7	MEAN	15.63	6.49	24.32	21.42	1.39	4.03	12.99
TÅG ERT	MEAN	12.31	4.74	20.55	17.96	0.59	2.80	11.43

Tab. 5.11 Mean totals of variables by site.

Classification Results[a]

		site number	Predicted Group Membership 1	2	3	4	5	6	7	8	9	Total
Original	Count	1	10	0	2	3	6	4	3	0	2	30
		2	0	27	0	0	2	0	0	1	0	30
		3	4	0	7	3	5	3	6	0	2	30
		4	3	0	3	14	2	2	6	0	0	30
		5	4	0	1	3	13	7	1	1	0	30
		6	3	0	1	3	5	15	3	0	0	30
		7	3	0	3	4	1	5	13	1	0	30
		8	3	0	0	0	0	1	0	19	7	30
		9	0	0	0	0	0	0	0	9	21	30
	%	1	33.3	.0	6.7	10.0	20.0	13.3	10.0	.0	6.7	100.0
		2	.0	90.0	.0	.0	6.7	.0	.0	3.3	.0	100.0
		3	13.3	.0	23.3	10.0	16.7	10.0	20.0	.0	6.7	100.0
		4	10.0	.0	10.0	46.7	6.7	6.7	20.0	.0	.0	100.0
		5	13.3	.0	3.3	10.0	43.3	23.3	3.3	3.3	.0	100.0
		6	10.0	.0	3.3	10.0	16.7	50.0	10.0	.0	.0	100.0
		7	10.0	.0	10.0	13.3	3.3	16.7	43.3	3.3	.0	100.0
		8	10.0	.0	.0	.0	.0	3.3	.0	63.3	23.3	100.0
		9	.0	.0	.0	.0	.0	.0	.0	30.0	70.0	100.0

a. 51.5% of original grouped cases correctly classified.

Tab. 5.12 Discriminant analysis classification results for all phases.

Classification Results[a]

		site number	Predicted Group Membership 1	3	4	5	6	7	Total
Original	Count	1	12	2	3	6	4	3	30
		3	4	7	3	7	2	7	30
		4	2	4	14	3	2	5	30
		5	5	0	3	15	6	1	30
		6	3	1	3	5	16	2	30
		7	4	3	4	1	5	13	30
	%	1	40.0	6.7	10.0	20.0	13.3	10.0	100.0
		3	13.3	23.3	10.0	23.3	6.7	23.3	100.0
		4	6.7	13.3	46.7	10.0	6.7	16.7	100.0
		5	16.7	.0	10.0	50.0	20.0	3.3	100.0
		6	10.0	3.3	10.0	16.7	53.3	6.7	100.0
		7	13.3	10.0	13.3	3.3	16.7	43.3	100.0

a. 42.8% of original grouped cases correctly classified.

Tab. 5.13 Discriminant analysis classification results for main body of phases.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.677	53.533	53.533	2.677	53.533	53.533
2	1.390	27.802	81.335	1.390	27.802	81.335
3	.438	8.752	90.088			
4	.325	6.490	96.578			
5	.171	3.422	100.000			

Extraction Method: Principal Component Analysis.

Tab. 5.14 Principal component analysis results for all phases.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.650	37.853	37.853	2.650	37.853	37.853
2	1.550	22.150	60.003	1.550	22.150	60.003
3	.888	12.682	72.685			
4	.751	10.725	83.410			
5	.529	7.558	90.968			
6	.393	5.619	96.587			
7	.239	3.413	100.000			

Extraction Method: Principal Component Analysis.

Tab. 5.15 Principal component analysis results for main body of phases.

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