Elfenbein und Artenschutz

Ivory and Species Conservation

INCENTIVS – Tagungsbeiträge der Jahre (2004 - 2007)

Proceedings of INCENTIVS – Meetings (2004 - 2007)

Bundesamt für Naturschutz

BfN – Skripten 228

2008

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BfN
Bundesamt für Naturschutz

Titelbild: Dr. D. Jelden, Bundesamt für Naturschutz (BfN)
Dr. A. Sliwa, Zoo Wuppertal

Bearbeitung:

J. Roth
Bundesamt für Naturschutz (BfN) / Federal Agency for Nature Conservation
Fachgebiet / Division Z 3.2
Konstantinstr. 110
53179 Bonn

Bearbeitung und verantwortlich für den Inhalt:

G. Bortolaso
INCENTIVS – International Centre of Ivory Studies
Johannes Gutenberg-Universität Mainz
Institut für Geowissenschaften
Becherweg 21
55099 Mainz

Die Beiträge der Skripten werden aufgenommen in die Literaturdatenbank ***„DNL-online“*** (www.dnl-online.de).

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Herausgeber: Bundesamt für Naturschutz
Konstantinstr. 110
53179 Bonn
Telefon: 0228/8491-0
Fax: 0228/8491-9999
URL: www.bfn.de

Druck: BMU-Druckerei

Gedruckt auf 100% Altpapier

Bonn – Bad Godesberg 2008

Inhalt

Vorwort

Seit Jahrhunderten fasziniert Elfenbein die Menschen in unterschiedlichen Bereichen. Zeitweise war dieses weiße Gold eine Wertanlage. Es wurde zu Schmuck und zu Kunstgegenständen verarbeitet. Nicht nur Elefantenelfenbein wurde verarbeitet, sondern auch Walrosselfenbein oder Flusspferdelfenbein. Das wertvollste Elfenbein war aber immer das des Elefanten. Dies führte in der Mitte des letzten Jahrhunderts vor allem wegen des immer stärker zunehmenden internationalen Handels fast zum Aussterben bestimmter Populationen des afrikanischen und des asiatischen Elefanten.

Aus diesem Grund wurde bereits 1975 der asiatische Elefant und dann auch im Jahr 1989 der afrikanische Elefant in den höchsten Schutzstatus des ‚Übereinkommens über den internationalen Handel mit gefährdeten Arten frei lebender Tiere und Pflanzen' (CITES) aufgenommen.

Lange Zeit war es nur schwer möglich Art, Herkunft oder Alter des verarbeiteten Elfenbeins zu bestimmen. Die Frage der Erkennbarkeit der Produkte und ihrer Zuordnung war dabei nicht nur interessant für Kunsthistoriker, sondern wurde immer mehr zu einem zentralen Problem für alle am Artenschutzvollzug beteiligten Behörden und wissenschaftlichen Einrichtungen. Denn während sich im Süden Afrikas die Elefantenpopulationen erholten und eine wirtschaftliche Nutzung der Bestände in Reichweite kam, sind die anderen Vorkommen nach wie vor stark gefährdet oder vom Aussterben bedroht. Für den internationalen Artenschutz war und ist es von großem Interesse, dass Methoden entwickelt werden, die zu einer möglichst genauen Unterscheidung verschiedener regionaler Herkünfte sowie zu einer genauen Altersbestimmung führen. Insbesondere die einerseits unverändert bestehende große Gefahr des illegalen Handels mit Elfenbein von gefährdeten Beständen und die auf der anderen Seite von der CITES Vertragsstaatengemeinschaft beschlossenen Lockerungen der strikten Handelsverbote für Elfenbein verschiedener südafrikanischer Populationen führte seit der 10. Vertragstaatenkonferenz zu brisanten Diskussionen. Mit der von der Universität Mainz entwickelten zerstörungsfreien Analysemethode zur Bestimmung der Herkunft von Elfenbein konnte nunmehr eines der damit verknüpften Probleme gelöst und u.a. in Zusammenarbeit mit dem Hauptzollamt Frankfurt am Main/Flughafen für die Praxis getestet werden.

Das Institut für Geowissenschaften an der Johannes Gutenberg-Universität in Mainz unter der Leitung von Prof. Dr. Wolfgang Hofmeister richtete auf Initiative des anerkannten CITES-Sachverständigen Dr. Arun Banerjee, das Forum INCENTIVS (International Centre of Ivory Studies) ein, in dem alle Fragen rund um das Thema Elfenbein eine Plattform erhalten. Ziel von INCENTIVS ist es, aktuelle Themen aufzugreifen, den derzeitigen Wissensstand aufzuarbeiten und gleichzeitig ein internationales Diskussionspodium für alle am Thema Elfenbein interessierten Gruppierungen zu bieten.

Bei den vorliegenden Artikeln handelt es sich um ausgewählte Tagungsbeiträge der Jahre 2004-2007 zum Thema „Elfenbein und Artenschutz".

Das Bundesamt für Naturschutz begrüßt und unterstützt aktiv die Forschung und die Einrichtung dieses Netzwerkes an der Universität Mainz. Denn nur wenn weitere effiziente Nachweismöglichkeiten entwickelt und angewandt werden, können Schutz und Nutzung der Elefantenbestände vertretbar nebeneinander stehen.

Prof. Dr. Beate Jessel
Präsidentin des Bundesamtes für Naturschutz

1 Einleitung

Elfenbein: Grundlage eines interdisziplinären Forschungsprojekts an der Johannes Gutenberg-Universität Mainz

Im Jahr 2003 ist im Institut für Geowissenschaften/Edelsteinforschung auf Initiative von Herrn Dr. Arun Banerjee INCENTIVS an der Johannes Gutenberg – Universität gegründet worden.

INCENTIVS, International Centre of Ivory Studies, verbindet Naturwissenschaften und Kulturwissenschaften, dient Behörden und Museen, versorgt Sammler und Kunstschaffende, macht sich in Artenschutz und Analyseentwicklung verdient. Neben der Durchführung zahlreicher Einzeluntersuchungen und den daraus resultierenden Materialgutachten hat INCENTIVS ein internationales Kooperationsnetz entwickelt und pflegt die interdisziplinären Kontakte zwischen Universitätsinstituten, Museen, Behörden, Forschungseinrichtungen etc. INCENTIVS tritt international auf Fachtagungen mit neuesten Ergebnissen und Erkenntnissen auf und stellt sich öffentlich der fachlichen Diskussion und der fachbezogen Information. Aufgrund der aktiven Einbindung von INCENTIVS in ein geowissenschaftliches Institut mit hervorragender materialanalytischer Ausstattung sind auch weiterhin Neuerungen und Verbesserungen bestehender Methoden zu erwarten. Mittlerweile haben im geowissenschaftlichen Umfeld die Zusammenhänge zwischen organischer Lebenswelt und anorganischer Materialwelt an Bedeutung stark gewonnen, und die „Biomineralisation“ wird als ein zukunftsfähiges, transdisziplinäres Teilgebiet der Materialwissenschaften gepflegt. Hierzu zählen auch diverse Neuinstallationen von Labor-Ausrüstungen, welche sich für die Untersuchung von Elfenbein und analogen Substanzen eignen und damit die Weiterentwicklung der Elfenbein-Forschung garantieren. Von herausragender Bedeutung ist insbesondere die Implementierung moderner, zerstörungsfreier Analysetechniken, die es garantieren, dass auch extrem empfindliche Unikate aus den Bereichen Kunst und Archäologie einer genauen Bestimmung zugeführt werden können, ohne dass das Untersuchungsobjekt in irgendeiner Art leidet. Die aktive wissenschaftliche Kooperation in internen und externen Forschungsprojekten sowie im Dienstleistungsbereich bringt eine stete Aktualisierung von Methoden- und Materialkenntnis mit sich. Neben der Deutschen Forschungsgemeinschaft als finanzieller Förderer sind insbesondere die bundesdeutschen Zollbehörden aufgrund der anhaltenden Versorgung mit aktuellem Untersuchungsmaterial positiv hervorzuheben. Aus deren monetären und materiellen Zulieferungen ist es möglich gewesen, eine wissenschaftliche Datenbank zu erstellen, die die Charakterisierung kulturhistorisch wertvoller Objekte erst umfänglich ermöglicht.

INCENTIVS ist zur rechten Zeit am rechten Ort entstanden. Aufgrund des intrinsisch interdisziplinären Charakters von Elfenbein zwischen Kunst, Kultur und Natur mit Anbindung an Ökologie und Ökonomie entwickelt sich INCENTIVS als aktives Bindeglied zwischen verschiedensten wissenschaftlichen Disziplinen und Anwendungen.

W. Hofmeister
Dekan des Fachbereichs Chemie, Pharmazie und Geowissenschaften
Johannes Gutenberg-Universität Mainz

2 Hintergrund

INCENTIVS (2003 – 2008) International Centre of Ivory Studies

Johannes-Gutenberg University Mainz, Germany

Ivory is an interesting object of research for many reasons. Today various groups like environmentalists, archaeologists, art historians etc., are engaged in research projects on ivory. However, due to a lack of proper communication among these different groups the research work done by these groups in their specific fields is known only to a limited number of scientists who are involved in similar fields related to ivory. It was found that an interdisciplinary network to improve this situation was missing. Due to this reason the **In**ternational **Cent**re of **Iv**ory **S**tudies (**INCENTIVS**) was installed in 2003 in the department of mineralogy and material sciences of Johannes-Gutenberg University in Mainz, Germany, in order to facilitate the communication between different research groups and also to inform the public about the current scientific and cultural projects on ivory. INCENTIVS of Johannes-Gutenberg University is a unique interdisciplinary working group in the field of ivory research.

The term ivory is commonly used for elephant ivory. However besides elephant ivory there are also other types of ivory, as for example, mammoth ivory, walrus ivory, hippopotamus ivory, narwhal ivory. Moreover, even in the case of elephant ivory one has to distinguish between ivory from savannah elephants and ivory from forest elephants. Besides that, ivory from African elephants is different from ivory from Asian (Indian) elephants. Sometimes even specialists find it difficult to identify the different types of ivory. The main aim of INCENTIVS is to identify the types and sources of ivory by using sophisticated methods.

Different German customs departments, for example the one at Frankfurt Airport, and other officials send regular consignments of seized objects made of ivory and ivory-like material to INCENTIVS for examination.

For the examination of such objects there are no simple tools and special methods had to be worked out. It should be mentioned that methods like DNA analysis are not applicable in such cases as this method is costly and also destructive.

Therefore alternative methods had to be tried for the investigation of ivory objects. It was found that Fourier Transform Infrared Reflection spectroscopy, Raman spectroscopy and ultra violet fluorescence spectroscopy were the three methods which were suitable for the examination of the seized ivory objects. These three methods are comparatively cheaper than the DNA analysis. However, the main advantage of the spectroscopic methods is that they are non-destructive: they do not cause any damage to the object under investigation and the seized objects can be returned to the customs departments unchanged after the forensic examination.

In the last five years INCENTIVS has successfully examined a huge number of seized ivory objects from customs departments and other law offices in Germany. In this way INCENTIVS has made a recognizable contribution to the protection of elephants

according to CITES. The founder of INCENTIVS was appointed CITES expert for ivory by the BfN (German Federal Ministry for Protection of Flora and Fauna) in 2005.
Moreover, the activities of INCENTIVS are not only confined to examining ivory objects from customs departments. Ivory artifacts from archaeological sites from different countries like Spain, Portugal and Morocco are also sent to this working group for expertise. An example of such international activities of INCENTIVS is the archaeological project on chalcolithic ivory from Spain in collaboration with the German Archaeological Institute (DAI) in Madrid. For the last three years this project has been sponsored by the German Federal Research Foundation (DFG).

It is concluded that the activities of INCENTIVS have already found national and international recognition and in the short period of its existence it has been able to establish valuable links between scientific and cultural aspects of ivory.

Dr. Arun Banerjee
CITES expert
Founder and Project leader of INCENTIVS
www.INCENTIVS.uni-mainz.de

3 Kurzfassung der Beiträge und Präsentationen

Überwachung von Artenschutz-Zusammenarbeit mit INCENTIVS

B. HOFMANN
Hauptzollamt Frankfurt am Main – Flughafen
- Artenschutzsachbearbeitung -

Im Jahre 1976 trat die Bundesrepublik Deutschland dem internationalen Artenschutzübereinkommen „CITES“ (**C**onvention on **I**nternational **T**rade in **E**ndangered **S**pecies of Wild Fauna and Flora) bei. In Deutschland ist das CITES als Washingtoner Artenschutzübereinkommen kurz: WA bekannt. Die dem WA beigetretenen Länder haben sich verpflichtet den Handel wildlebender Tiere und Pflanzen (sowie aus ihnen hergestellte Erzeugnisse) zu kontrollieren, um deren Überleben zu sichern. Dieses Abkommen wird in den Vertragsstaatenkonferenzen immer wieder den aktuellen Änderungen angeglichen. Das Abkommen wurde in der Europäischen Union durch die Verordnung (EG) 338/97 und in der Bundesrepublik Deutschland durch das Bundesnaturschutzgesetz umgesetzt.

In Deutschland ist der Zoll für die Überwachung und Durchführung der im WA für den internationalen Handel festgelegten Kontrollmaßnahmen zuständig. Insbesondere Elefanten gehören zu den bedrohten Tierarten. Deshalb wurden sowohl für den asiatischen Elefanten (*Elephas maximus*) als auch für den afrikanischen Elefanten (*Loxodonta africana*) strenge Schutzmaßnahmen festgelegt; beide Elefantenarten sind in Anhang I des CITES gelistet.

Über den Flughafen Frankfurt als eine internationale Drehscheibe des globalen Warenverkehrs werden immer wieder Gegenstände (z.B. Schnitzereien) eingeführt, die aus Elfenbein vom afrikanischen bzw. asiatischen Elefant hergestellt wurden. Dabei wird häufig von den Zollbeamten festgestellt, dass die vorgeschriebenen Genehmigungen nicht vorliegen. Allein im Jahr 2005 wurden fast 200 Objekte aus Elfenbein vom Elefanten durch das Hauptzollamt Frankfurt am Main – Flughafen beschlagnahmt, im Jahr 2006 sogar rund 1500 Stücke.

Nachdem immer mehr Vorkommen von fossilen Mammut entdeckt werden und immer öfter Schmuck aus – nicht geschütztem - Mammutelfenbein hergestellt wird, muss im sich anschließenden rechtlichen Verfahren verifiziert werden, ob das Elfenbein vom Mammut oder vom Elefanten stammt.

Vom Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit werden unabhängige Personen und Stellen als Sachverständige anerkannt. Herr Dr. Arun Banerjee mit dem „Incentivs“-Team des Fachbereichs Geowissenschaften der Johannes Gutenberg Universität Mainz wurde als Sachverständiger für das Washingtoner Artenschutzübereinkommen anerkannt und im Bundesgesetzblatt als solcher veröffentlicht. „INCENTIVS“, hat mit der zerstörungsfreien Bestimmung der Herkunft des verwendeten Materials schon sehr oft dazu beigetragen, Schmuggel von Elfenbeingegenständen aufzudecken.

Elephant Conservation and the Ivory Trade

[1]REIFENSTEIN, V., [1]KITSCHKE, C. & [1]*ZIEGLER, S.

[1] WWF Germany, Rebstoeckerstrasse 55, 60326 Frankfurt, Germany

* Corresponding author, email: sziegler@wwf.de

Keywords: Ivory trade, CITES regulations, conservation and preservation of elephant, habitat

Schlagwörter: Elfenbeinhandel, CITES Bestimmungen, Rettung von Elefanten, Habitat

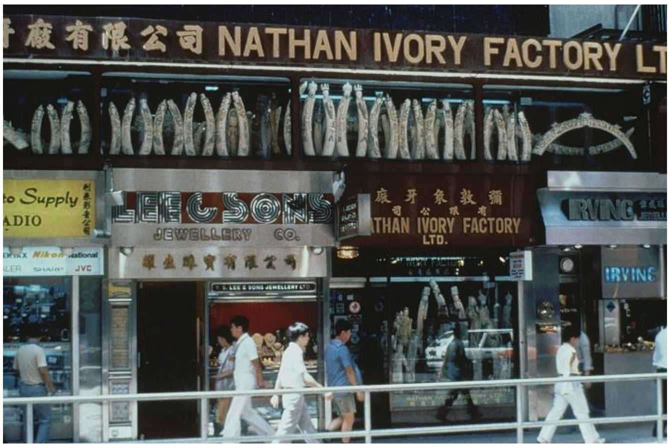
Zusammenfassung

Der internationale Handel mit Elfenbein hat in vielen afrikanischen Ländern in den 1980er Jahren zu einem dramatischen Rückgang der Bestände geführt. Vor allem in Ost- und Zentralafrika wurden durch nicht nachhaltige Jagd sowie Wilderei pro Jahr bis zu 62.000 Tiere getötet. Um die Elefantenpopulationen Afrikas zu schützen, hat die internationale Gemeinschaft 1989 den Afrikanischen Elefanten auf Anhang I des Washingtoner Artenschutzübereinkommen (CITES) gelistet und damit jeglichen internationalen kommerziellen Handel mit Elfenbein und anderen Elefantenprodukten verboten. Das internationale Handelsverbot blieb nicht ohne Kritik, denn verschiedene südafrikanische Länder behaupteten, dass einige der Elefanten-Verbreitungsstaaten mit rückläufigen Populationen den Bann als Ersatz für eine effektive Gesetzgebung und Strafverfolgung auf nationaler Ebene missbrauchen und damit Jahrzehnte des Missmanagements kaschieren. Mittels vorliegender Bestandsschätzungen aus 33 Elefanten-Verbreitungsstaaten für den Zeitraum von 1981 bis 2007 haben wir untersucht, inwieweit diese Kritik gerechtfertigt ist. Unsere Ergebnisse weisen darauf hin, dass die Elefantenpopulationen der Elfenbeinküste, der Demokratischen Republik Kongo und der Zentralafrikanischen Republik kaum vom Handelsbann profitiert haben, denn dort gehen die Bestände seit 1981 kontinuierlich zurück. Die Daten von ETIS, dem Informations- und Überwachungsprogramm für den Handel und Schmuggel von Elefantenprodukten, zeigen zudem, dass der illegale Handel mit Elfenbein vor allem in einigen Ländern Zentralafrikas seit 2004 ansteigend ist. Positiv haben sich dagegen Verbesserungen von Schutzmassnahmen und Elefantenmanagement im Kontext der CITES Anhang I Listung für die Elefanten in Ostafrika entwickelt: Dort nehmen die Bestandszahlen seit Beginn der 1990er Jahre stetig zu.

Summary

The international ivory trade remains one of the world’s most controversial wildlife trade issues. Throughout the last four decades, public attention has focused primarily on trade in ivory derived from the African elephant. Following a decade in which African elephant populations in certain regions may have decreased by as much as 80 percent because of widespread hunting and poaching for ivory, in 1989 the international community acted through the Convention on International Trade in Endangered Species

of Wild Fauna and Flora (CITES) to list the species in Appendix I, the maximum level of protection afforded by the treaty. The ban was introduced to help safeguard the African elephant from illegal killing on a clearly non-sustainable scale. The Asian elephant has previously been listed in CITES Appendix I in 1975. Several southern African countries argued that in support of the ban, some elephant range states with declining populations used the ban as a substitute for effective law enforcement at the national level and were covering up decades of mismanagement. We evaluated this concern and its implication and calculated population trends across 33 elephant range states. Although many populations in southern and eastern Africa have shown signs of recovery, elephants in West and Central Africa are still at the brink of extinction if threats are not successfully mitigated in the near future. We found that the trade ban in 1989 had apparently no tangible conservation impact on elephant populations in Ivory Coast, Democratic Republic of Congo, and Central African Republic were the population trend remains negative since 1981. This may explain the recorded background levels of poaching that mainly take place in the forests of Central Africa. Furthermore, data from the ETIS database indicate that illicit trade in ivory has been increasing since 2004.



Shop window of an ivory dealer
Hong Kong 1988
Credit: © WWF-Canon / Mauri RAUTKARI

1 Elephant conservation status

For centuries people have viewed elephant ivory as a valuable commodity, used for carvings, jewellery, and other artefacts. Sculptures made of ivory are known to science from more than 30,000 years ago (Conrad 2003). The Trojans wore buckles and pins fashioned from the elephant's tusks, and adorned their war chariots with bits of ivory. Two thousand years ago, the Romans honoured illustrious men with handsomely chiselled writing tablets and sceptres carved in ivory. From prehistoric times to the present day, ivory has been sought as a luxury with multiple applications. Thus, the killing of elephants to satisfy the demand for ivory has presumably been the major factor in reducing elephant populations throughout most of history (Kingdon 1997).

African elephant

The African elephant *Loxodonta africana* once occurred throughout Africa, but disappeared already from the north of the Sahara in the 6th century AD (Meester & Setzer 1977). During the 17th century, ivory mainly derived from sources in West Africa. The species' abundance was further reduced when Europeans started to establish permanent trading posts throughout Africa in the 18th and 19th century, expanding the trading routes, and thus increased the supply for timber and ivory (Fage 1969).

African elephant (*Loxodonta africana*), herd on the move. Amboseli National Park, Kenya. Distribution Sub-Saharan Africa
Credit: © WWF-Canon/Martin HARVEY

The decline of the elephant populations eventually accelerated in the 20th century. Particularly *L. africana* suffered tremendously due to widespread hunting and poaching for ivory. Several million African elephants might have roamed throughout Africa at the beginning of the 20th century (Milner-Gulland & Beddington 1993). The number may have declined from three to five millions in the 1930s and 1940s to fewer than 400,000 remaining individuals in the early 1990s (Douglas-Hamilton et al. 1992; Said et al. 1995). Poaching skyrocketed in the 1980s and was fuelled by an increasing international demand, with Japan and the USA the largest importer countries for raw ivory (Thomsen 1988). At that time, up to 100,000 elephants were killed annually and certain regions lost 80 percents of their populations due to poaching and the illicit trade of ivory (Eltringham & Malpas 1980; Douglas-Hamilton 1987; Cobb & Western 1989; Merz & Hoppe-Dominik 1991, Alers et al. 1992; WWF 1997, 1998).

African elephant *Loxodonta africana* Elephant ivory confiscated from poachers
Credit: © WWF-Canon / Martin HARVEY

Nowadays *L. africana* can still be found in 37 range states in Sub-Saharan Africa, but certain populations hardly exceed a few hundred individuals. At the time of the last continent wide assessment in 2007, the African elephant population was calculated to be at least 472,000 individuals, with possible numbers exceeding 690,000 elephants (Blanc et al., 2007).

Asian elephant

The Asian elephant *Elephas maximus* once roamed the forests from China to Iraq, but today, its distribution is patchy and fragmented (Anonym. 2005). Like its African cousin, *E. maximus* was traditionally hunted for its tusks for thousands of years. Additionally, its habitat rapidly diminished due to the growth of human population and the associated agricultural expansion. Consequently, in most range countries of *E. maximus*, elephant numbers crashed drastically during the 19th century (Olivier 1978). At the start of 20th century, Asia contained approximately 100,000 elephants in the wild (WWF 2002). In 1990, their numbers were thought to be between 34,500 and 54,000 individuals (Santiapillai et al. 1990). As recently as 1995, only 25,600 to 32,750 Asian elephants were thought to remain in the wild (Anonym. 2006). Since then, several populations have dwindled still further, and scientists fear that current populations may have fallen well below 1995 estimates.

Herd of Asian elephants in Rajaji National Park, North India. Credit: © WWF-Canon / A. Christy WILLIAMS

Sumatran elephant (Elephas maximus sumatrensis) in the remote region of the Minas elephants' camp. Tesso Nilo, Riau Province, Sumatra, Indonesia
Credit: © WWF / Volker KESS

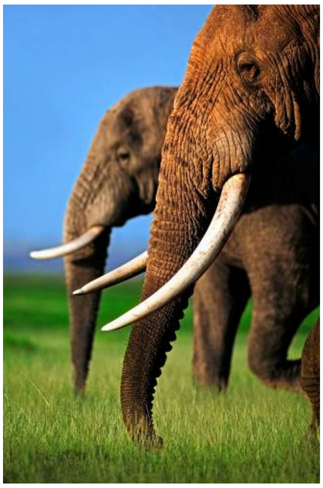
Table 1: Population estimates and trends of African elephants from 1981 to 2007. Elephant population data from 1995 and 2007 have been aggregated from the "Definite", "Probable", "Possible" and "Speculative" categories to produce indicative national totals.

Range states	**1981**	**1989**	**1995**	**2007**	**Population trend**		
West Africa					1981-1989	1989-1995	1989-2007
Benin	1.250	2.100	1.550	1.223	+	-	-
Burkina Faso	3.500	4.500	2.600	4.994	+	-	+
Ghana	970	2.500	2.300	1.429	+	-	-
Guinea	800	560	1.000	350	-	+	-
Ivory Coast	4.800	3.600	2.200	965	-	-	-
Liberia	2.000	1.300	1.800	1.676	-	+	+
Mali	780	640	800	654	-	+	+
Niger	800	440	800	102	-	+	-
Nigeria	1.820	1.300	1.600	828	-	+	-
Senegal	370	140	40	10	-	-	-
Togo	150	380	200	65	+	-	-
Central Africa							
Central Afr.Rep.	31.000	22.000	9.300	3.334	-	-	-
Cameroon	5.000	32.000	17.000	15.387	+	-	-
Chad	15.000	3.100	3.100	6.435	-	**0**	+
Congo	10.800	42.000	33.000	22.102	+	-	-
Democratic Rep of Congo	376.000	112.000	84.000	23.714	-	-	-
Equator Guinea	1.300	500	400	1.330	-	-	+
Gabon	13.400	74.000	82.000	70.746	+	+	-
East Africa							
Ethiopia	900	8.000	2.400	1.760	+	-	-
Kenya	65.056	16.000	26.600	31.636	-	+	+
Rwanda	150	50	80	117	-	+	+
Somalia	24.323	2.000	250	70	-	-	-
Sudan	133.772	22.000	0	300	-	-	-
Tanzania	203.900	22.000	98.000	167.003	-	+	+
Uganda	2.320	3.000	1.850	6.559	+	-	+

Southern Africa							
Angola	12.400	18.000	8.200	2.530	**+**	**-**	**-**
Botswana	20.000	51.000	80.200	175.487	**+**	**+**	**+**
Malawi	4.500	2.000	2.300	2.727	**-**	**+**	**+**
Mozambique	54.800	7.000	14.900	26.088	**-**	**+**	**+**
Namibia	2.300	5.700	12.000	19.103	**+**	**+**	**+**
South Africa	8.000	8.200	10.000	18.507	**+**	**+**	**+**
Zambia	160.000	32.000	33.000	29.231	**-**	**+**	**-**
Zimbabwe	49.000	52.000	82.000	99.107	**+**	**+**	**+**

2 International conservation action

The sharp decline of elephant numbers in Africa and Asia prompted swift international action shortly after the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) entered in force in 1975. The Asian elephant *E. maximus* has been listed in CITES Appendix I in 1975, thus prohibiting international commercial trade in ivory and other elephant products from the Asian elephant species (O’Connell-Rodwell & Parry-Jones 2002). In 1977, the African elephant was placed in Appendix II of CITES, which means commercial trade in ivory is regulated according to certain requirements. The Parties to CITES agreed in 1985 to put in place a quota system for tightening controls on the ivory trade. In 1989, the international efforts to halt the ivory trade culminated in the listing of the African elephant in CITES Appendix I to cut off supply to the markets. However, the so-called Somalia Amendment established specific down-listing criteria for the transfer of stable or increasing populations back to Appendix II, thus addressing concerns of certain elephant range states that not all elephant populations qualified for placement on Appendix I (Dublin et al. 1997).



African elephant (*Loxodonta africana*), in the foreground, bull with large tusks. Amboseli National Park, Kenya.
Distribution Sub-Saharan Africa
Credit: © WWF-Canon/ Martin HARVEY

Applying these criteria, Namibia, Botswana, Zimbabwe, and South Africa successfully down-listed their elephant populations on CITES Appendix II in 1997 and 2000, respectively. Furthermore, the down listing of their elephant populations on Appendix II qualified these countries to conduct a one-off sale of their ivory supplies, but only with permission from CITES. The convention developed strict conditions under which such kind of sale is allowed. The countries are permitted to sale only ivory descended from governmental stocks. The conditions commit the amount, origin and size of the ivory products, further on the requirements within the import country as well as the time of trade. The achieved benefits must be used for elephant conservation and livelihood programmes to improve the situation of local communities.

Elephant tusks stored away under extreme security measures in the ivory stock pile of the Kruger National Park, South Africa. February 2006
Credit: © WWF-Canon/Folke WULF

In 1999 the first one-off sale took place to Japan. A second sale was approved by CITES in 2002 but not realized, because the conditions were not fully met (Stephenson 2007). On the CITES Conference of the Parties in 2007, all African states have agreed on a compromise in trade with raw ivory. They have decided that South Africa, Namibia, Botswana, and Zimbabwe can dispose every ivory from governmental stocks, registered until 31st January 2007, in a one-off sale. After this transaction the ivory trade for these four countries will be ceased for at least nine years.

3 The impact of the trade ban

Since the global CITES trade ban took effect in 1990, there have been conflicting views about its impact on the ivory trade. The immediate result was an apparent reduction in illicit trade and a decline in the scale of certain key ivory markets. Against a backdrop of growing international pressure, numerous importing countries began introducing domestic legislation to stop importation of raw ivory (Dublin et al. 1997). All ivory-producing states were facing the fact that the demand for ivory in the major, pre-ban consumer nations had fallen off sharply. A virtual demise of the demand for ivory in North America and Western Europe and reductions of up to 50 percent in Japan were described by O'Connell & Sutton (1990) shortly after the trade ban was imposed. Furthermore, it quickly became evident that the drop reflected a true and lasting change in market demand for ivory, which put those countries in a dilemma that wished to earn revenues from the sale of ivory. Botswana, Malawi, Mozambique, South Africa, Zambia, and Zimbabwe, some of them had not suffered the sharp decline of their elephant populations in the 1970s and 1980s, did see their options for funding elephant conservation programmes undermined (Dublin et al. 1997). When trade was banned, Botswana lost about 53 percent of its potential direct use values (Bennett 1997). Several southern African countries argued that in support of the ban, some elephant range states with declining populations used the ban as a substitute for effective law enforcement at the national level and were covering up decades of mismanagement.

In order to verify this concern and its implication for today's elephant management, we calculated population trends across 33 elephant range states with data from the African Elephant Database (Blanc et al. 2007; Douglas-Hamilton 1992; Douglas-Hamilton 1980) for the pre-ban period from 1981 to 1989, the first few years after the ban was imposed from 1989 to 1995, and the post-ban period from 1989 to 2007. We decided to assess population trends for two different time horizons after the trade ban in order to rule out the impact of short-term effects, such as civil disorder, on the elephant populations. The results of this assessment are summarized in table 1.

Population trend lines for the period from 1981 to 1989 showed declining elephant numbers for 19 of the 33 assessed African elephant range states. Trend lines for the post-trade ban period from 1989 to 1995 pointed out a slightly improved overall picture to the extent that in 16 of the 33 range states, numbers of elephants decreased. The period from 1989 to 2007 depicted 18 out of 33 range states, in which trend lines indicated declining elephant numbers. Interestingly, elephant populations in four southern African countries (Namibia, South Africa, Botswana, and Zimbabwe) already started to increase years before the trade ban was imposed. This might indicate that the elephant populations in those countries were better managed and protected than in many other range states were poaching was rampant in the 1980s. However, the apprehension of the four southern African countries to become targets of increased poaching activities due to the cease of the direct use values after the trade ban did not materialize: elephant numbers in Namibia, South Africa, Botswana, and Zimbabwe have continued to increase since 1989.

Moreover, the trade ban in 1989 had apparently no tangible conservation impact on elephant populations in certain West and Central African countries (Ivory Coast, Democratic Republic of Congo, and Central African Republic) were the population trend remains negative since 1981. The continued killing of elephants has often been attributed to the effects of civil disorder (Dublin & Jachmann 1991) and a high perception of corruption, which together lead to poor law enforcement. This may explain the recorded background levels of poaching that mainly takes place in the forests of Central Africa (Blake & Hedges 2004). Particularly the new increasing demand of ivory in China has significantly influenced the increasing illicit trade since 1995 and the international ivory market as a whole (Stephenson 2007).

However, in certain countries the ban on ivory trade clearly changed the economic environment for elephants as it helped the illegal hunting to collapse. In Kenya, for instance, the average annual number of elephants killed by poaching decreased from 3,500 elephants per year in the early 1980s, to about 50 in 1993. Furthermore, the Tanzanian elephant population has considerably increased, from 22,000 in 1989 to more than 150,000 in 2007, and continues to increase.

4 Monitoring illegal killing and illicit trade

Despite the official trade ban, ivory was still moving within Africa but little was known regarding the exact amounts involved or how much of this was actually leaving the continent (Dublin & Jachmann 1991). While there was evidence that some sort of ivory leaking out of government-held stocks, the origin of most illegal ivory shipments was not always clear. Therefore, in the early 1990s, the African elephant range states stated the need to develop a monitoring system to track the illegal killing of elephants in the field (Hunter & Milliken 2004). The decision to establish this monitoring system (MIKE – Monitoring the Illegal Killing of Elephants) was agreed by CITES Parties at CoP 10 in Resolution Conf. 10.10. It was considered of primary importance having a simple system of international reporting of incidents of illegal hunting as a baseline against which changes in trends can be detected. Thus, the overall aim of MIKE is to build institutional capacity within the range States for the long-term management of their elephant populations (CITES 1994). Furthermore, the system allows for assessing whether observed trends of illegal killing of elephants are related to CITES decisions on ivory trade and population listings (Hunter & Milliken 2004). Prior to the development of MIKE, there was evidently no centralized way to track elephant mortalities and feed this information into the CITES process. MIKE tracks the illegal killing of elephants through a site-based monitoring programme in some 70 locations in 29 African elephant and 12 Asian elephant range states. At each site, data on elephant numbers, illegal killings and other deaths, law enforcement effort and other factors are collected in a standardized way (TRAFFIC 2007).

The CITES Secretariat monitors ivory trade through the Elephant Trade Information System (ETIS), which is managed by TRAFFIC, the joint wildlife trade monitoring programme of WWF and IUCN. ETIS is a comprehensive information system to track illegal trade in ivory and other elephant products. It shares identical objectives as set out for MIKE, with the difference that it aims to record and analyse levels and trends in illegal trade, rather than the illegal killing of elephants (Hunter & Milliken 2004). Analysis of the ETIS data state that a total of over 322 tonnes of ivory has been seized and reported to ETIS between 1989 and 2006. The number of seizures ranges from a minimum of 289 cases in 1989 to a maximum of 1,008 cases in 1990, with a mean value of 630 cases per year. The ivory volumes varied between 9,668 kilograms in 1995 and 33,090 kilograms in 2002, with a mean value of 17,883 kilograms each year. A steady decline in seizures of illicit ivory could be registered from 1989 until 1995, followed by an increase from 1996 to 1998. Thereafter regressive ivory seizures were reported until 2004, again followed by an upward movement from 2005 onward. In conclusion, a number of 11,331 ivory seizures have been reported to ETIS by 82 countries or territories between 1989 and 2006. These data imply that at least 164 countries or territories worldwide are implicated in the illicit ivory trade. The evaluation of ETIS data indicate that illegal trade in ivory is most directly related to the presence of large scale unregulated domestic ivory markets in several African and Asian countries. Due to poor law enforcement, weak regulatory oversight of the illegal markets can prevail. The five countries most heavily implicated today in the illegal ivory trade are: Cameroon, China, the Democratic Republic of Congo, Nigeria, and Thailand. Of this group only China shows significant progress in taking action against illicit ivory trade (Milliken et al. 2007).

5 Conclusion

Data from ETIS indicate that the level of illicit trade in ivory is once again increasing from 2004 onwards. This trend line is cause for concern as it points out that measures taken to date to control the trade in African elephant ivory were not completely successful. Furthermore, population trends derived from the African Elephant Database indicate that intense poaching is widespread throughout much of Central Africa, leading to recent declining population numbers in five of seven range states in the region. However, elephants in Africa and Asia are not only sought after for their ivory. Habitat loss and deterioration in habitat is occurring throughout elephant range, and there is anecdotal evidence that elephants are hunted for their meat in Central Africa (Stephenson 2007). Although many populations in southern and eastern Africa have shown signs of recovery, elephants in West and Central Africa are still at the brink of extinction if threats are not successfully mitigated in the near future.

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Imitations and substitutes for ivory: A short history

G. BORTOLASO
INCENTIVS – International Centre of Ivory Studies, Johannes Gutenberg-Universität Mainz

Keywords: Ivory imitations, ivory substitutes, vegetable ivory
Schlagwörter: Elfenbeinimitate, Elfenbeinersatz, pflanzliches Elfenbein

Zusammenfassung

Es ist international anerkannt, dass der Begriff Elfenbein Zähne oder Stosszähne von Säugetieren beschreibt, damit auch Walross, Killer- oder Pottwal, Narwal, Flusspferd und Warzenschwein zu den Lieferanten dieses kostbaren Materials gehören. Das Handelsverbot von 1975 für asiatisches Elfenbein, erweitert 1990 auf afrikanische Elefanten, hat die Suche nach efenbeinähnlichen Materialien in den letzten Jahren deutlich belebt. Aufgrund seiner Seltenheit und des Verkaufspreises wurde Elfenbein bereits in der Antike nachgeahmt. Wenn Elfenbein nicht vorhanden war, wurden ähnliche Materialien wie Knochen und Muscheln so geschnitzt und behandelt, dass sie danach aussahen. Mit der Erfindung von Zelluloid um 1870, als der bedeutendste Vorgänger von Kunststoff, begann die Epoche der künstlichen Elfenbein-Imitierung. Darüber hinaus sind die Nüsse von afrikanischen und südamerikanischen Palmen *Hyphaene thebica* und *Phytelephas macrocarpa* pflanzliche Imitate. Weniger bekannt als Quelle für pflanzliche Imitate ist die indische *Aeschyomene indica*, die den sogenannten Sholapit enthält. Zurzeit existiert auf dem Markt eine breite Palette an natürlichen und künstlichen Produkten, die verstärkt Möglichkeiten der Fälschung und des Betrugs ermöglichen.

1 Introduction

The word “ivory” has today a broader meaning than in the past. According to the most recent classifications the term “ivory” applies to the tusks of elephant as well as to many more materials. Besides the Asian and African elephant animals like mammoth, walrus, sperm whale, narwhal, hippopotamus, wart hog and helmeted hornbill are sources of the precious material. As Espinoza and Mann write [1], “Ivory can correctly be used to describe any mammalian tooth or tusk of commercial interest which is large enough to be carved or scrimshawed”.

It may be asked why we need to differentiate all these similar things. In several professional domains there is a huge interest in understanding as much as possible about ivory. The categories are those of art historians, archaeologists, customs officers and of course gemmologists. The identification of type and provenance of ivory is in fact for different reasons of outmost relevance for all of them. To art historians and archaeologists precise data on an ivory find help reconstructing the ancient trade routes and identifying the social status of the owner. Customs officers need to distinguish among the different materials as some of them are subject to export restrictions. Gemmologists want to know what kind of ivory or ivory substitute they are dealing with, since each of them has a different price on the market of rare natural materials.

2 Substitutes for elephant ivory

2.1 Mammoth *(Mammuthus primigenus)*

Although mammoths have been extinct for 10.000 years (Fig 1), their geographical range, namely Alaska and Siberia, allowed the preservation of their tusks, which are found buried under the frosted earth. Since some decades *Mammuthus primigenus* is one of the few legal sources of high quality, carvable ivory (Fig. 2). The up to 3-4 m long spiralled tusks come from two modified upper incisors and can weight up to 150 kg. Trade in mammoth ivory is legal.

Fig. 1
Woolly Mammoth, reconstruction
Royal Museum of British Columbia
(Photo licensed under. Creative Commons Attribution 2.0, Author: rpongsaj)

Fig. 2 - Modern mammoth jewelry

2.2 Walrus *(Odobenus rosmarus)*

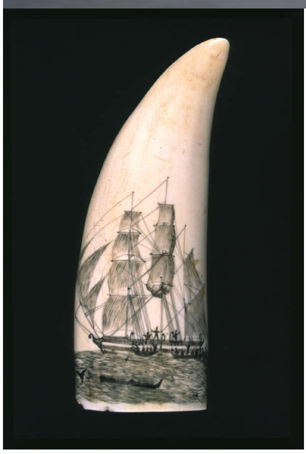
These bulky marine mammals (Fig. 3) live in the Arctic Ocean and Sub-arctic seas of the Northern Hemisphere. Their prominent tusks – occasionally reaching up to 1 m in length – have made them sought after by the ivory hunters. Arctic peoples have hunted them too for their meat, fat and bone. Walruses feed on bivalve mollusks and their tusks are thought to have a mere ornamental function. They also serve as an anchor to hold them on mud bottoms and chase bentonic mollusks or to jump out of the sea water and move on the icy soils. *Odobenus* originally means “walking on its own teeth”.Trade in walrus ivory is banned by CITES.

Fig. 3
Walrus, Alaska

2.3 Sperm Whale *(Physeter catodon)*

In the exceptionally large head of the Sperm Whale (Fig. 4) a long lower jaw hosts 20–26 pairs of cone-shaped teeth, each 8–20 cm long (Fig. 5 and 6). Each tooth can weigh as much as one kilogram. The use of the teeth is debated; it is currently thought that they are used in fighting between males of the same species. Trade in walrus ivory is banned by CITES.

Fig. 4 - Sperm Whale (Photo licensed under “Scarred Giant” by Chris Hamam)



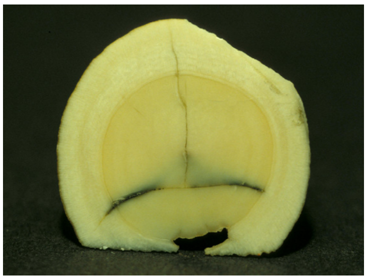


Fig. 5 - Tooth‘s cross-section

Fig. 6 - Scrimshaw carved out of a Sperm Whale tooth

2.4 Narwhal *(Monodon monoceros)*

Narwhals (Fig. 7) belong to the Whale species and live eastwards from the Canadian Arctic through much of Russia. They have become famous due to their unusual dentition. By males one of the two teeth growing from the upper jaw develops in a form of a spiralled straight tusk. Its length varies between 1.5 and 2.5 m and it can weigh up to 10 kilos. Females are virtually toothless, occasionally they may develop one or two tusks. In ancient times the unusual shape of the tusk originated the legend of the mythical unicorn. The species is somewhat endangered by human hunting but it has not reached a protection status, therefore narwhal ivory can be legally sold and bought.

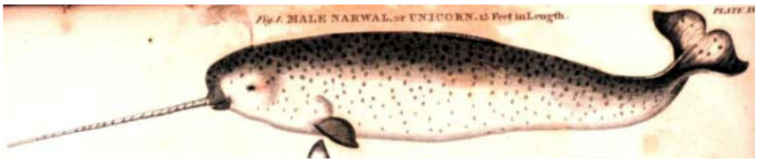


Fig. 7 –Narwhal (Old drawing)

2.5 Hippopotamus *(Hippopotamus amphibius)*

The canine teeth of the hippopotamus (Fig. 8) grow life long, reaching up to 60-70 cm in length. In male hippos a canine tooth can weigh up to 4 kg, whereas in females they do not exceed 1 kg. Hippo tusks are a deadly weapon due to their sharpness. Hippo ivory cannot legally circulate on the market.

Fig. 8
Hippopotamus
(Photo licensed under. Creative Commons - Attribution 2.5, Author: Nv8200p)

2.6 Wart hog *(Phacochoerus aethiopicus)*

Wart hogs (Fig. 9) belong to the pig family and can reach up to 1.5 meters in length and 150 kg in weight. The protruding and constantly growing upper canine teeth are used as weapons by the animal and sought after as ivory material. The upper wart hog teeth can grow to 23 cm and shows an almost rectangular cross section. The trade in wart hog ivory is legal.

Fig. 9
Wart hog, Namibia

2.7 Helmeted hornbill (*Rhinoplax vigil*)

This bird, which can reach up to 1.20 m in height, features on the upper part of its bill a casque made of keratin, unlike many other similar species. The original yellow colour of the casque will turn red outside, as the animal rubs it with the oil produced by its preen gland. In all Asia this material has always been highly appreciated. Today the trade in hornbill ivory is banned.

3 Ivory-like materials

Aside of these tooth/tusk materials some other ivory-like materials are currently used as ivory substitutes, namely bone, shell, and the so called vegetable ivory. Following is a brief introduction to some sources of vegetable ivory.

Sources of the so-called vegetable ivory are the following plants.
- *Phytelephas macrocarpa (12 Species)*
- *Aeschynomene aspera*
- *Hyphaene indica*
- *Attalea funifera*
- *Raphia vinifera*
- *Corypha umbracaulifera*
- *Mauritia flexuosa*
- *Borassus flabellifer*

3.1 Tagua palm tree (*Phytelephas macrocarpa)*

This palm lives in Columbia, Ecuador, Peru. Its nuts have been used since 19th century as ballast for transatlantic cargo shipments. In 1866 the German Hermann Donath begins a buttons production in Schmölln (East Thuringia) which becomes extremely successful. Gradually 29 buttons factories employ half of the city work force reaching in 1913-14 the highest production. With the advent of the manufactured materials the button industry dismissed the natural imitation of ivory and the Schmölln local industry lost its relevance also due to the strong competition of the Eastern European countries.

Presently only two button factories are still in business. This plant is not threatened by extinction.

3.2 Sholapith *(Aeschynomene aspera)*

Shola (i.e. hat plant) is obtained from the soft stem pith of Aeschynomene aspera in West Bengal and Assam. Shola is a wild plant that belongs to the beans family and grows in marshy waterlogged areas. Hats made of this material were widely used by the British officials in colonial times. The cortex or cores of the plant, showing a diameter of 3.5 cm, are used as a carving material. Its milky colour makes sholapith easily mistaken for ivory, although weight and hardness are much lower than those of ivory. The material extracted from this plant is not restricted by environmental regulations.

4 Ivory imitations

Beginning with the last decades of the 19th century the *plastic era* gradually offered a differentiated choice of ivory imitations (Table 1). Features common to all new ivory imitations are an affordable price and a high similarity to the elephant ivory. Typical fault is a lesser durability compared to real ivory and to the tooth/tusk materials in general.

Table 1: Manufactured Ivory Imitations

Trade Name	Composition	Manufacturer and/or Distributor	Date of invention	Tests
Celluloid	Cellulose nitrate	Hyatt's Celluloid Manuf. Co., USA	1870	Under hot water smells like vinegar or old camphor
Galalith (Ivorina®, Erinoid, Keronyx, Lactoid, Ameroid, Calorn)	Casein + phormaldeid	Numberless	1897	Smells like milk when tested with hot needle
Bakelite	Phenol-formaldehyde resin	Numberless	1907-9	Unknown
Ivorite	Casein + hardener	Yamaha Corp., Japan	20th cent.	Smells like milk when tested with hot needle
Elforyn	Plastic + mineral basis	Bachmann Kunststoff Techn., Germany	21th cent.	Unknown
GPS	Polyester	GPS Agency Ltd. England	21th cent.	Unknown

Table 2: Mineral Ivory Substitutes

Ivoriyte	Precipitate of Magnesium, Calcium and Silica	Natural product	none	Harder than ivory. 5 or 5-1/2 on the Mohs' scale

4.1 Celluloid

Due to a shortage of ivory, a USA manufacturer of billiard balls offered a $ 10,000 reward for an ivory substitute. The Hyatt brothers from New York discover the new material, a cellulose nitrate, first patented in 1870 under the name *celluloid.* Celluloid cannot be moulded, but rather carved and shaped, just like ivory. From celluloid G. Eastman developed in 1885 the first transparent photographic film. Main use of celluloid was in objects like combs, fountain pens, knives handles, etc. Due to its extremely high inflammability, today few products are made out celluloid, among them ping-pong balls (Fig. 10).

Fig. 10
Ping-pong balls

4.2 Galalith (milk stone)

It was discovered in Germany in 1897 by accident, following the request to develop school blackboards that would not burn. In his Hannover-based factory Wilhelm Krische experimented on the milk protein casein. Instead of a new blackboard material he discovered a horn-like plastic (Fig. 11 and 12). Since 1898, when it was patented, galalith has been used for electric components, as well as for jewellery and any kind of accessories. In 1913 about 30 million litres of milk were used in Germany to produce galalith. This material lost gradually its importance with the increasing use of oil derived products, which were cheaper and less fragile.

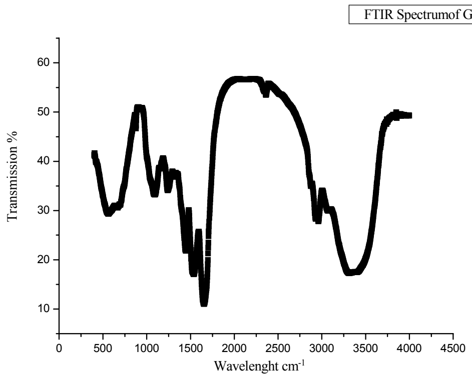


Fig. 11 – FTIR Spectrum of Galalith

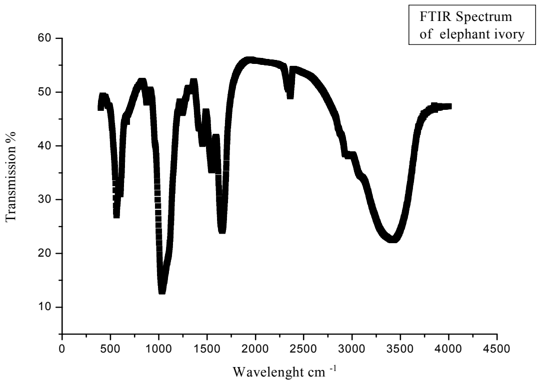


Fig. 12 – FTIR Spectrum of elephant ivory

4.3 Bakelite

Invented and patented in 1909 by the Belgian chemist Leo Baekeland, immigrated to the USA in 1900. Baekeland first discovered a phenol-formaldehyde resin which was brittle, by resubmitting it to heat and pressure he obtained a thermo set material that he named *Bakelite.* In the Thirties the new material was so popular, that several hundreds factories were active in Germany. Main uses for Bakelite were home and cooking objects, such as telephones or pan handles, along with office objects, switches or electric sockets (Fig. 13). Bakelite is still nowadays in use as an electric insulator.

Fig. 13
Radio made of
Bakelite

4.4 Ivorite® or Ivorine

Ivorite® is a casein derived product, patented by Yamaha Corporation, and extensively used for piano keys, musical instruments as well as sculptures (Fig. 14).

Fig. 14
Indian goddess made of Ivorine

4.5 Elforyn

The new product is the result of the joint research of the Professional School for Ivory Carving in Michelstadt and the German plastic company Bachmann. It is made of a plastic material mixed with a mineral content. Besides an excellent workability, characteristics features of this material are no water absorption, fluorescence, resistance to cleaning agents, fats, acids and alkalis.

4.6 GPS

The polyester resin, traded solely by GPS Agencies, a Connecticut based firm, is a substitute for ivory complying with the requirements of the following English institutions: Victoria & Albert Museum, English Heritage and The National Trust.

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Distinction between African and Asian Ivory

A. BANERJEE, G. BORTOLASO. W. DINDORF
INCENTIVS – International Centre of Ivory Studies, J. Gutenberg-Universität Mainz

Keywords: X-ray diffraction, Raman spectroscopy, CITES, elephant ivory
Schlagwörter: Röntgendiffraktion, Raman Spektroskopie, CITES, Elefantenelfenbein

Zusammenfassung

Die Nachfrage nach dem wertvollen und äußerst attraktiven Material Elfenbein hat dazu geführt, dass Elefanten heute zu den bedrohtesten Arten zählen. CITES (das Washingtoner Artenschutzübereinkommen von 1989) hat den Handel mit Elfenbein generell verboten, erlaubt jedoch heute ausnahmsweise einigen wenigen afrikanischen Staaten, einmal im Jahr eine begrenzte Menge von Elfenbein zu exportieren. Der illegale Handel nicht autorisierter afrikanischer und asiatischer Länder geht jedoch weiter. Um dem entgegenzuwirken, muss man legal und illegal gehandeltes Material unterscheiden können. Dies kann eine DNA-Analyse leisten, die aber nicht zerstörungsfrei und außerdem recht kostspielig ist. Aus diesem Grund wurde nach zerstörungsfreien Alternativmethoden gesucht.

Die Grundlagen der Untersuchung von Elfenbein sind seine physikalischen und chemischen Eigenschaften, die von der Nahrung und dem Habitat des Tieres abhängen. Die Untersuchungskriterien sind dabei die innere Struktur des Stoßzahns, nämlich die Größe der Kristallite des Dahllits und die Zusammensetzung des Kollagens. Die Untersuchungsmethoden sind: die optische Mikroskopie, die FTIR-Spektroskopie und die Mikro-Raman-Spektroskopie. Die optische Mikroskopie konzentriert sich auf die Beobachtung der sogen. Schregerlinie. Diese Struktur entsteht durch die dreidimensionale Anordnung der Dentinkanälchen im Stoßzahn. Mit Hilfe der Schregerlinie kann man die verschiedenen Arten von Elfenbein wie folgt voneinander unterscheiden:
afrikanisches Waldelefantenelfenbein > ca. 123°
afrikanisches Steppenelefantenelfenbein > ca. 118°
asiatisches Elefantenelfenbein > ca. 112°
Die Größe und die Anordnung der Dahllitkristalle unterscheiden die Elfenbeinarten von einander. Bei der Infrarot- und der Mikro-Raman-Spektroskopie wird die Elfenbeinprobe mit Infrarotlicht bzw. mit einem Laser einer bestimmten anderen Wellenlänge bestrahlt. Dadurch werden die Moleküle des Elfenbeins in Schwingung versetzt. Jede Elfenbeinart hat ihre typischen Schwingungsmuster. Anhand dieser *Fingerprint*banden kann man die Art identifizieren, ohne die Probe zu beschädigen. Darüber hinaus ist es möglich, durch die chemische Untersuchung des Pulvers eines Elfenbeins mit Hilfe der Elementaranalyse die verschiedenen Elfenbeinarten zu identifizieren.

Abstract

Ivory is a precious and beautiful material. Since prehistoric times till today it is being used as a working material by artists and craftsmen for sculptures and ornaments all over the world. Due to the high demand of ivory many elephants have been killed in the last decade. Today elephants belong to the most endangered species. According to **CITES** (**C**onvention on **T**rade in **E**ndangered **S**pecies) there is a worldwide ban on ivory. Recently four African countries (Botswana, Zimbabwe, Namibia and South Africa have been allowed to sell legally a limited quantity of ivory once a year. But the poachers from other African countries are offering plenty of illegal ivory. The same is also true for the Asian countries. In order to distinguish legal materials from illegal ones the source of ivory must be located. To date this is not possible, as there is no practicable method, except the DNA-analysis. As known, the DNA-analysis is a destructive method and it can not be applied for the investigation of sculptures made of ivory. The present paper shows how the source of ivory can be traced by non destructive spectroscopic methods: It is not only possible to discriminate Asian ivory from African ivory, but it also enables us to locate the specific African countries which are involved in the trade with illegal ivory. Due to this reason the present investigation can supply valuable information to the customs departments and to the authorities engaged in the protection of elephants.

Fig. 1 and 2 - Carvings of African (left) and Asian (right) ivory

2 Types and habitats of elephants

The habitats of elephants are located in Africa and Asia (Fig. 3). Worldwide there are three kinds of elephants:

a) African elephant (*Loxodonta africana*)
   a) Savannah elephant (*Loxodonta africana africana*)
   b) Forest elephant (*Loxodonta africana cyclotis*)

b) Asian elephant (*Elephas maximus*)

a) African elephants (Fig. 5 and 6)
  1a) African savannah elephants are found mainly in eastern and southern part of the continent lying south of the Sahara Desert.
  1b) African forest elephants, which are smaller than the savannah elephants inhabit in the forests of western equatorial Africa and Congo.

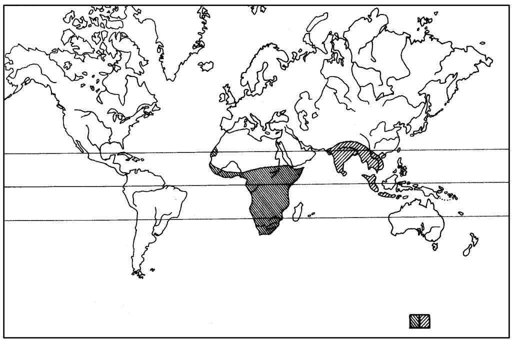
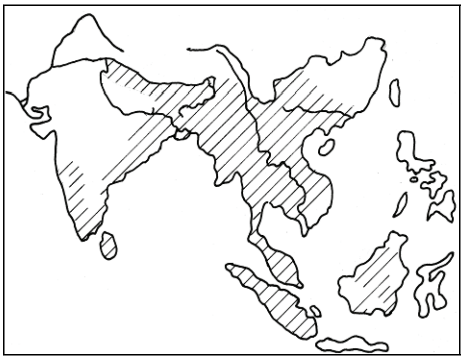


Fig. 3 -Worldwide distribution of elephants

b) Asian elephants
According to the recent WWF surveys the Asian elephant (Fig. 4 and 7) once ranged from the Tigris-Euphrates river system in the west, throughout Asia south of the Himalayas, east to China. Its present distribution covers only a fraction of its former range and the species now generally occurs as scattered, isolated populations form south India and Sri Lanka eastwards through Assam to Vietnam and extreme South Yunan Province in China, and south to islands of Sumatra and Borneo. Today Asian elephants are found mainly in the following countries: Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Laos, Malaysia, Myanmar, Nepal, Sri Lanka, Thailand and Vietnam.



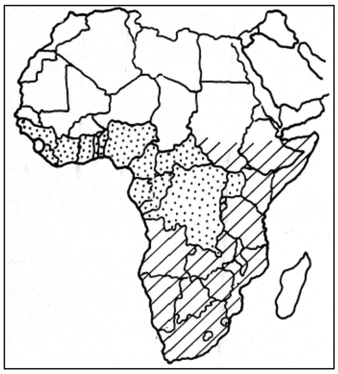


Fig. 4 and 5 - Distribution of elephants in Asia (left) and Africa (right). Dotted areas show the habitats of forest elephants and striped ones those of savannah elephants within Africa

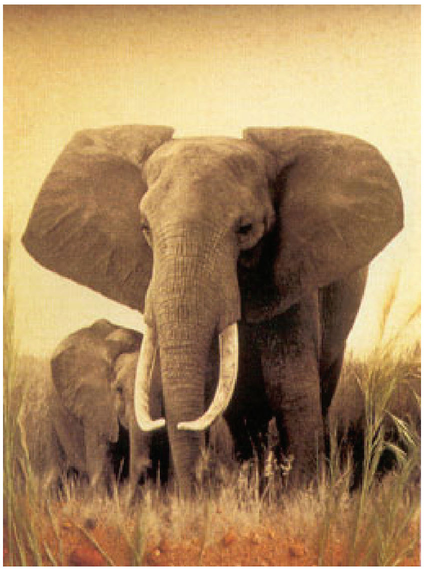


Fig. 6 and 7 -African (left) and Indian elephant

Table 1- Number of wild elephants living in the Asian countries
(update 2003, Zurich Zoo)

Country	Minimum	Maximum
Bangladesh	200	350
Bhutan	60	150
Burma (Myanmar)	3,000	7,000
Cambodia	400	600
China	200	250
India	14,190	19,000
Indonesia (Kalimantan)	100	500
Sumatra (Indonesia)	1,260	1,800
Laos	780	1,200
Malaysian peninsula	1,250	1,450
Sabah (Malaysia)	1,130	1,620
Nepal	50	90
Sri Lanka	2,100	3,000
Thailand	2,500	3,220
Viet Nam	1,500	2,000
TOTAL	**28,610**	**41,930**

3 Ivory: Morphology and internal structure

The tusks of an elephant are deeply implanted into the long cylindrical sockets which are located in the bones in the anterior portion of its upper jaw. The tusk of an elephant has three distinct regions: pulp cavity in the centre, dentine in the middle and cementum in the outmost border.

Odontoblastic cells line the pulp cavity and are responsible for the production of dentine. Dentine, which is the main component of ivory, forms a layer of consistent thickness around the pulp cavity and comprises the bulk of the tusk. Dentine is a mineralized tissue with an organic matrix of collagenous proteins. The inorganic component of dentine is dahllit, a phosphate mineral. Dentine contains a microscopic structure called dentinal tubules which are micro-canals that radiate outward through the dentine from the pulp cavity to the exterior of the cementum border. These canals have different configurations in different ivories and their diameter ranges between 0.8 and 2.2 microns. Their length is dictated by the radius of the tusk. The three dimensional configuration of the dental tubules is under genetic control and is therefore a characteristic unique to the order. The configuration of the dental tubules are observed on the polished cross sections of elephant tusks and are called Schreger structure, named after W. Schreger (1880).

The tusks grow continuously during the whole life of an elephant from persistent pulps at the base of the tusk. Tusks of African Savannah elephants are generally much longer than those of Asian elephants. Tusks of bulls of African savannah elephants are sometimes more than 3 m long and may weigh up to 90 kg. Tusks of female Savannah elephants are somewhat smaller and have more slender tusks. Tusks of African forest elephants are much smaller than those of savannah elephants. Tusks of Asian bull elephants are generally about to 2 m long. The female of this species has no tusk.

Fig. 8 - Four tusks of savannah elephant and a tusk of forest elephant in the middle

Fig. 9 and 10 - Hollow part of the tusk (left side) and solid part of the tusk in a longitudinal and cross section (right side)

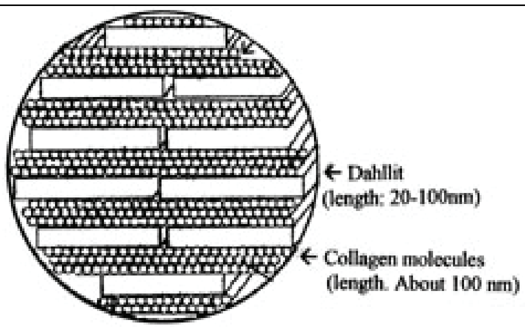


Fig. 11 - Schematic drawing of a cross section of elephant tusk showing dahllit crystallites with collagen fibres

4 Methods of identification

4.1) Optical Microscopy
4.2) Scanning Electron Microscopy (SEM)
4.3) Transmission Electron Microscopy (TEM)
4.4) FTIR Spectroscopy
4.5) Raman Spectroscopy
4.6) Elementar Analysis

4.1 Optical Microscopy

The identification of the so called Schreger lines is the first step leading to the attribution of the ivory. Schreger lines occur only in ivory from elephant and mammoth and not in other types of ivory, like walrus ivory and hippopotamus ivory.

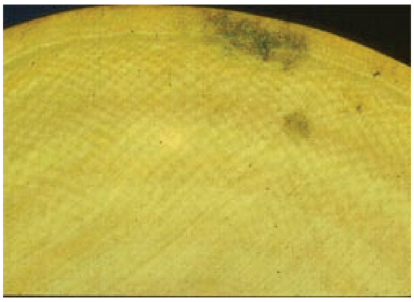
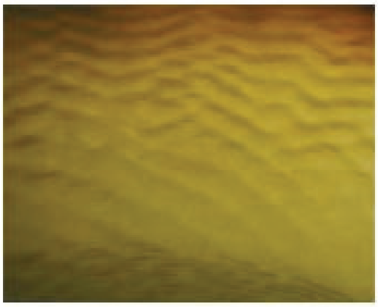


Fig. 12 and 13 - Cross sections of ivory showing Schreger structure of savannah elephant (left) and Asian elephant (right)



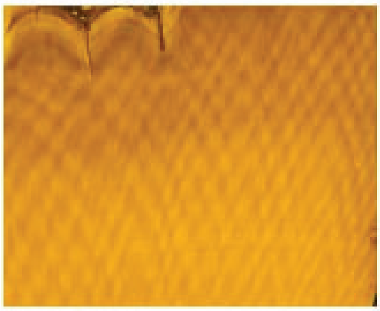
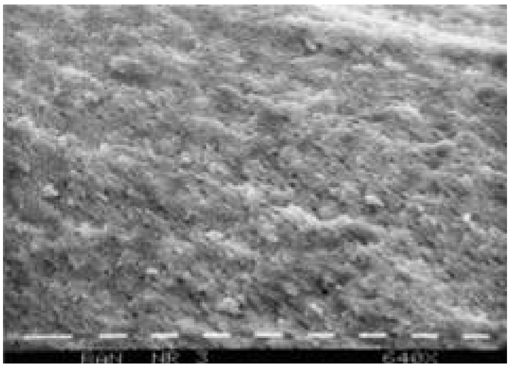


Fig. 14 and 15 - Cross sections of ivory showing Schreger structure of forest elephant (left) and mammoth (right)

4.2 Scanning Electron Microscope (SEM)



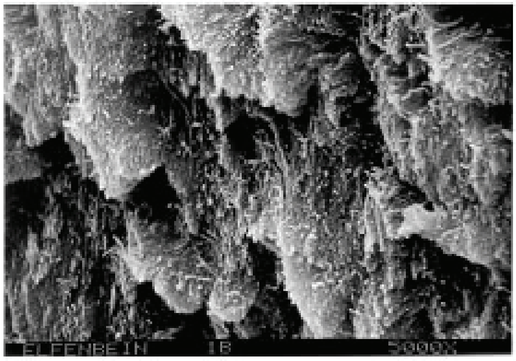


Fig. 15 and 16 - SEM-micrographs of ivory showing dental tubules (left, 640X) and fibrous structure (right, 5000X)

4.3 Transmission Electron Microscope (TEM)

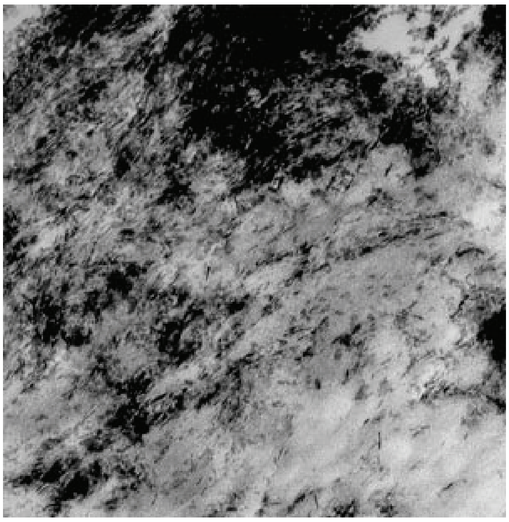
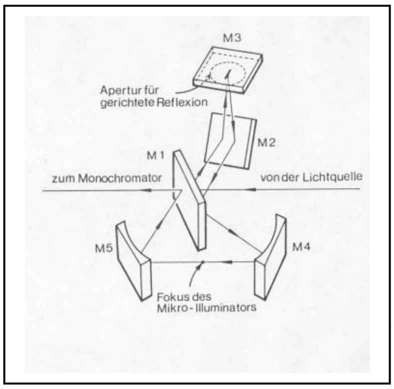


Fig. 17 - TEM-micrograph showing dahllit crystallites (black “strokes”) in ivory embedded in a matrix of collagen (white areas)

4.4 Fourier Transform Infrared Spectroscopy (FTIR)

In cases where the visual examination fails to produce any satisfactory results, the most effective methods for the non-destructive identification of ivory are based on spectroscopy, namely Fourier Transform Infrared Spectroscopy and Raman Spectroscopy.

The general principle of infrared spectroscopy is that it deals with the interaction of infrared light with organic and inorganic compounds. It is a useful technique for the identification of a wide range of substances-solids, liquids and gases. The FTIR spectrum of a substance is uniquely characteristic of that substance, and therefore it can be used for the purpose of its identification. There are two possibilities to apply the FTIR-technique for investigations of samples, e.g. the potassium bromide (KBr) pellet and the reflectance technique.



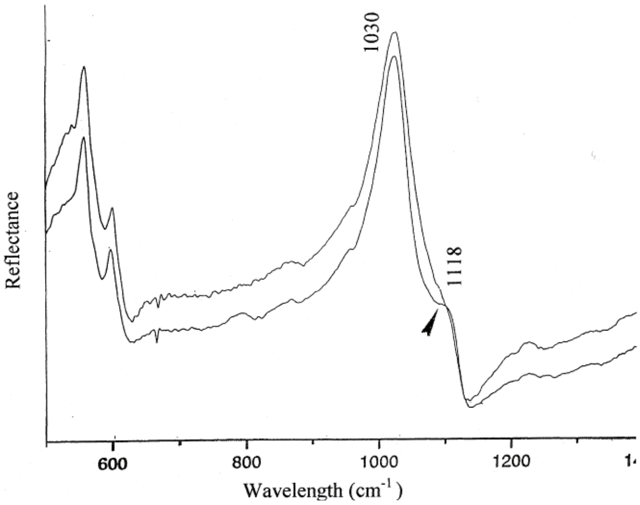


Fig. 18 and 19 - Construction scheme of a reflection equipment used in a FTIR spectrometer (left) and FTIR reflection spectra showing the characteristic differences (shoulder at 1180 cm^{-1}) between Asian and African ivory (right).

4.5 Raman spectroscopy

The Raman spectroscopy is complementary to the FTIR spectroscopy. The technique is named after its inventor Sir C.V. Raman. Similar to the FTIR spectroscopy organic and inorganic solids, liquids and gases can be investigated by this technique. Raman spectroscopy involves illuminating a sample with monochromatic light and using a spectrometer to examine light scattered by the sample. A laser is used as a source of incident photons that gain or lose energy when they interact with molecules in a sample, producing frequency shift in the scattered photons. The frequency shift corresponds to the energy difference between the incident and scattered photon and is termed Raman shift. Different materials have different vibration modes, and therefore characteristic Raman spectra.

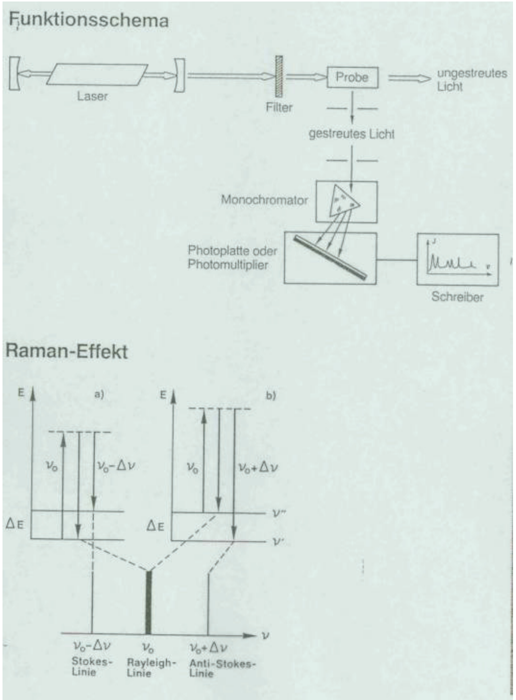


Fig. 20 - Schematic drawing of the working principle of Raman spectroscopy

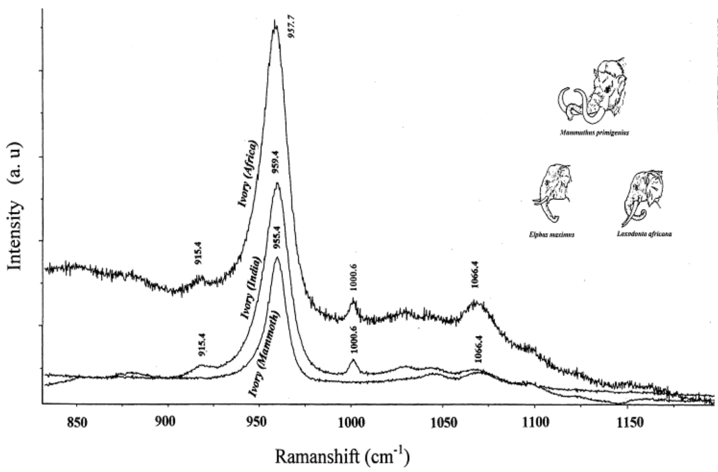
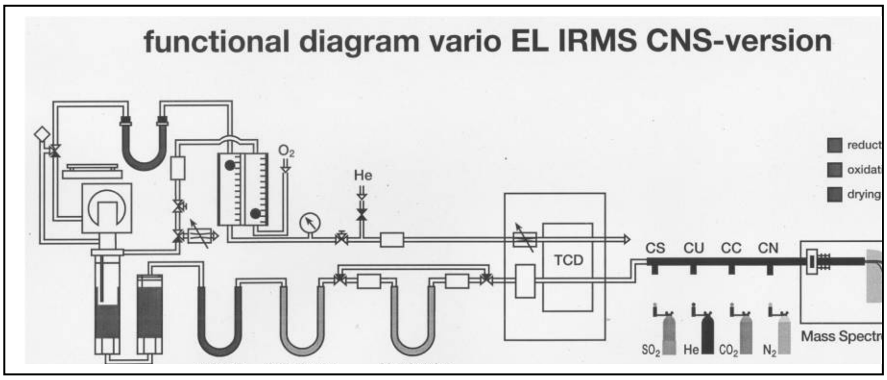


Fig. 21 - Raman spectra showing typical bands of different types of ivory

4.6 Elemental Analysis

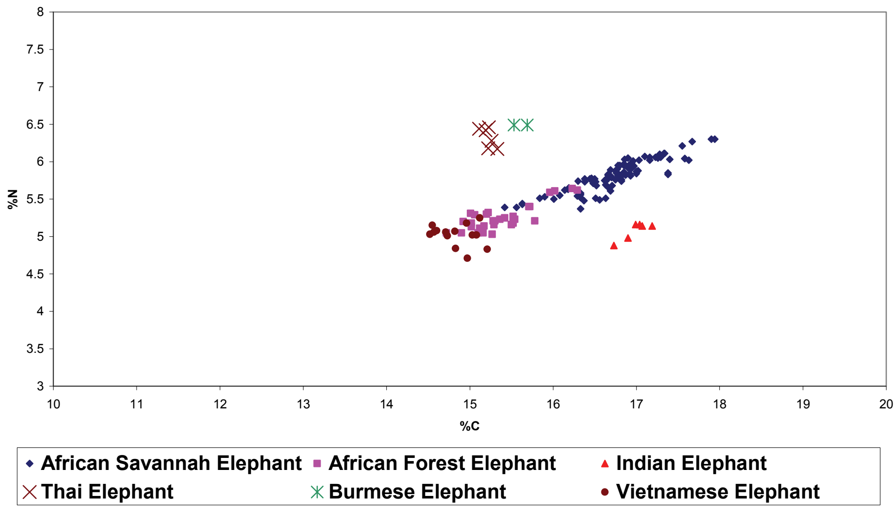


Semi-quantitative analysis of ivory was done for the elements carbon (C), nitrogen (N) and hydrogen (H) using an automatic elemental analyzer Vario EL apparatus (Elementar Analysensystem, Hanau, Germany). The working principle is shown. The principle of this method comprises three steps:

a) burning the sample at 1150ºC
b) catalytic processing of the generated gases (CO_2, H_2O and N_2) produced by burning and
c) separation and detection of the different gases by thermoconductive detectors (TCD).

The amount of each gas was determined by TCD and a calibration curve. Percentage of each gas was calculated considering the amount of weighed sample.

Table 2 - Elemental Analysis: Correlation between C% versus N% of different types of ivory



5 Discussion

From prehistoric times ivory has been used for sculptures and ornaments all over the world. But due to high demand of ivory in the last decades a large number of elephants have been killed and the total number of elephants both in Africa and Asia has been significantly reduced. Therefore in order to protect the elephants an international agreement was imposed, CITES (Convention on International Trade with Endangered Species). Since 1989 trade with ivory is banned all over the world.

Ivory carving has an old tradition in Asia. Due to the ban of ivory the situation in the ivory market in many Asian countries has changed in the last years. As published in the TRAFFIC Bulletin in 2004, the ivory carving industry in South and South-east Asia, i.e. Thailand, Myanmar and Viet Nam, is gradually changing. A 2002 and 2003 survey of the main ivory carving workshops in the three countries shows that the processing of this material is falling in Viet Nam (Hanoi), has collapsed in Thailand (Phayuha Kiri) and tends to be stable in Myanmar (Mandalay). Although concerns for the conservation of the elephant species do not play a major role, due to religious convictions most of the carvers in Myanmar and Thailand share a high regard for these animals and do not want to responsible for their mortality. This attitude does not seem to be widespread among the Vietnamese carvers, although they also express the wish of devoting their skills to the production of high quality items.

It seems that a general trend has established among the ivory carvers in the surveyed countries over the last years, which implies that the carving activity should be aimed at producing objects of indubitable cultural and artistic significance. For products of lesser quality (e.g. chop sticks, tourist curios, etc.) which represent the great majority of the processed ivory, substitutes such as bone, bone powder mixed with resin, jade or even plastic are already and could be more largely used.

However, although the Government authorities in the Asian and European countries are trying their best to control the ivory trade, there is a regular supply of illegal ivory from many African countries particularly to the big cities in China, Japan, and Thailand. Tracing the sources of illegal ivory is therefore a fundamental problem for CITES.

6 Conclusions

The identification of source of ivory is based on the physical and chemical characteristics of the material which in their part depend on the food eaten by the elephants in a particular region. For example, the chemical composition of ivory of forest elephants, which live mainly on leaves differ significantly from that of ivory of savannah elephants which live mainly on grass.
The qualities of ivory, such as texture and hardness also depend on the eating habits of the elephants. Ivory from savannah elephants is called “hard” ivory and that from forest elephant is called “hard” ivory. Ivory from Asian elephants are very similar to that of forest elephants. In trade, particularly in Japan, hard ivory is in demand because it is

used there for making *hanko*s, personal name stamps. It is said that most of the hard ivory used in Japan for *hankos* are illegal, because the import of hard ivory, obtained from the tusks of forest elephants is not allowed. In recent years some African countries have been allowed by CITES to export a limited quantity of ivory. Therefore there are both legal and illegal materials in the ivory market. The main problem for CITES is to distinguish between legal and illegal ivory.

As shown in the present paper the source of ivory can be successfully detected by spectroscopic and chemical methods. Moreover the non-destructive methods are very useful for the investigation of sculptures and ornaments made of ivory.

Investigation of quality of commercial mammoth ivory by means of X-ray Powder Diffraction (Rietveld method) and FTIR Spectroscopy

A. BANERJEE*, G. BORTOLASO, W. HOFMEISTER, I. PETROVIĆ-PRELEVIĆ, B. KIEWISCH
J. Gutenberg University, Mainz
*Corresponding author

Keywords: X-ray diffraction, Rietveld method, Fourier-Transform-Infrared spectroscopy, Transmission Electron Microscopy, CITES, mammoth ivory

Schlagwörter: Röntgendiffraktion, Rietveld-Methode, Fourier-Transform-Infrarot Spektroskopie, Transmission-Elektronen-Mikroskopie, CITES, Mammutelfenbein

Zusammenfassung

Elfenbein ist ein einzigartiges Beispiel für Biomineralisation. Es ist hart, aber elastisch und daher vorzüglich geeignet für außergewöhnliche Kunstgegenstände: vor ca.30.000 Jahren wurde der Ulmer *Löwenmensch* aus Mammutelfenbein geschnitzt. Mammutelfenbein dient heute wieder als Werkstoff, denn es ist eine Alternative zu dem 1989 durch das Washingtoner Artenschutzübereinkommen unter Schutz gestellte Elefantenelfenbein. In Deutschland werden große Mengen von Mammutelfenbein verarbeitet. Das Material stammt aus Nordostsibirien. Die ursprüngliche Beschaffenheit des Mammutelfenbeins, Farbe und Dichte, wurde im Laufe der Zeit durch Verwitterung mehr oder weniger verändert. Dabei ändert sich in erster Linie die innere Struktur des Materials. Das handelsübliche Material wird in drei verschiedenen Qualitäten angeboten: Qualität A (nicht verwittert), Qualität B (wenig verwittert) und Qualität C (stark verwittert). Ziel der vorliegenden Untersuchung war, den Zusammenhang zwischen den folgenden drei Faktoren aufzuzeigen: zwischen der inneren Struktur, dem Verwitterungsgrad und der Qualität des Elfenbeins.

Mammutelfenbein besteht aus Dentin, nadelförmigen Karbonathydroxyapatitkristallen (früher als *Dahllit* bezeichnet), welche in einer Kollagenmatrix eingebettet sind. Die Veränderung des Mammutelfenbeins besteht u.a. darin, dass das Karbonathydroxyapatit rekristallisiert wird.
INCENTIVS hat sieben sibirische Mammutelfenbeinproben aus seiner Sammlung untersucht. Diese Proben zeigten drei Verwitterungsgrade und damit drei verschiedene Handelsklassen. Bei der Untersuchung wurden zwei Methoden angewandt: (a) die Röntgen-Pulverdiffraktion-Rietveld-Methode sowie (b) die Fourier-Transformation-Infrarot(FTIR)-Spektroskopie. Die erstgenannte Methode (a) gilt als äußerst aufschlussreich bei der Strukturuntersuchung von allen gut oder weniger gut kristallisierten Substanzen. Da das Karbonatbioapatit nur schwach kristallin ist, fiel die Wahl der Untersuchungsmethode logischerweise auf die Rietveld-Methode.
Die FTIR-Methode beruht auf der Interaktion von Infrarotlicht mit den organischen und den anorganischen Komponenten eines Materials, in unserem Fall dem Kollagen und

dem Karbonathydroxylapatit. Die FTIR-Daten wurden mit dem Perkin Elmer FTIR Spektrometer 1725X aufgezeichnet. Die FTIR-Transmission-Spektren basierten auf der Untersuchung verschiedener Mammutelfenbeinproben in Form von Pulvern, welche mit Hilfe der Kaliumbromid-Pellet-Technik hergestellt wurden. Die Kristallinität des Karbonathydroxylapatits wurde ermittelt, indem man den Spaltfaktor (SF) aus den FTIR-Spektren berechnete. Dieser Faktor basiert auf der zunehmenden Trennung der FTIR-Absorptionsbanden zwischen 565 und 605 cm-1. Darüber hinaus wurde aus den FTIR-Spektren die relative Erhaltung von organischem Material und der Einbau von Karbonat im Verhältnis zu Phosphat bestimmt: die Intensität der Amid- und der Phosphat-Banden wurden mit der Intensität der Karbonat- und der Phosphat-Banden verglichen.

Alle mit der Rietveld-Methode untersuchten Mammutproben zeigen Peaks von lediglich einer Phase, dem schwach kristallisierten Apatit. Bei zunehmendem Verwitterungsgrad kann man eine deutliche Zunahme der Länge der Karbonathydroxyapatitkristalle erkennen: je verwitterter das Material, desto länger sind die Kristalle.

Diskussion und Schlussfolgerung

- Ein Ergebnis der Rietveld-Untersuchungen ist die Erkenntnis, dass die Kristallgröße der Hauptgrund für die Erweiterung der Apatitreflektion ist.
- Es sollte darauf hingewiesen werden, dass TEM (Transmission-Elektronen-Mikroskopie) lediglich die nadelähnliche Form der Kristalle sichtbar gemacht hat, es aber nicht möglich war, ihre genauen Dimensionen zu messen wegen des Vorhandenseins der darüber liegenden Kollagenschichten.
- Die Analysen der Röntgendaten gaben Aufschluss über die Größe der Karbonathydroxylkristalle. Die Messungen ergaben, dass je verwitterter die Probe ist, desto länger sind die Kristalle: die Kristalle der am stärksten verwitterten Proben sind größer als 300 Ä. Kristalle der nicht verwitterten Proben haben eine Länge von 169 Ä. Bei weniger verwittertem Material beträgt die Länge zwischen 219 und 235 Ä. Diese Ergebnisse können jedoch wegen der geringen Zahl untersuchter Proben nicht verallgemeinert werden.
- Die Ergebnisse der Röntgen-Rietveld-Untersuchungen und die der FTIR-Analysen sind übereinstimmend bis auf eine einzige Abweichung. Eine Erklärung hierfür mag sein, dass der untersuchte Teil der Probe besser erhalten war als der Rest.
- Entsprechend der FTIR-Analyse enthält eine Mammutelfenbeinprobe mit höheren SF-Werten größere Karbonathydroxyapatitkristalle.
- Die FTIR-Untersuchung über das Verhältnis zwischen Verwitterung und gradueller Veränderung der chemischen Zusammensetzung des Mammutelfenbeins ergab, dass sowohl das Amid-Phosphat-Verhältnis als auch das Karbonat-Phosphat-Verhältnis mit dem Grad der Verwitterung zunimmt.
- Bemerkenswert ist die direkte Korrelation zwischen der zunehmenden Durchschnittsgröße der Karbonathydroxyapatitkristalle und der Abnahme des Kollagengehalts des Mammutelfenbeins.

1 Introduction

Ivory is a unique product of biomineralisation. It is formed by the mineralisation of connective tissue in the tusk and teeth of some animals like elephant and mammoth. It is a rock-hard fibrous material of high elasticity and its fibrous structure is unique for creating intricate ornamental articles (Fig. 1). Since prehistoric times mammoth ivory has been used as a working material. Several figurines, including a lion headed man, and also ornaments carved out of mammoth ivory were found near Ulm in Germany. The objects are about 32,000 years old and they are still intact. In the last years mammoth ivory has come back again: Due to the worldwide ban on trade in elephant ivory according to the **C**onvention on **I**nternational **T**rade in **E**ndangered **S**pecies of Wild Fauna and Flora (CITES) regulation, since 1989 mammoth ivory is being used as an alternative for elephant ivory by the manufacturers in China, Japan and also in Germany. Large quantities of mammoth ivory are being imported to Germany, where the small town of Erbach in Odenwald is famous for its ivory carving industry. Almost all mammoth ivory comes from Northeast Siberia where huge numbers of mammoth tusks are excavated every year. The tusks are well preserved due to permafrost. However not all material is workable. Consignments of raw mammoth ivory from Siberia generally include three qualities of material as follows: best quality A (white and unweathered), second quality B (yellow and slightly weathered), and third quality C (brown and extremely weathered). Colour and quality of mammoth ivory change due to diagenesis and hydrolysis under the soil. It was proved by chemical and spectroscopic investigation that colour and quality of mammoth ivory change due to loss of its main chemical constituents, e.g. carbon, nitrogen and sulphur [1]. Similar weathering processes occur also in bone [2].

Mammoth ivory is made of dentine, which is a composite material. Dentine consists of needles of carbonate hydroxyapatite or bio apatite (previously called dahllite [3, 4, 5]), $Ca_{10}(PO_4)_6(OH)_2$, which are embedded in a matrix of collagen. Carbonate hydroxyapatite crystallites have variable dimensions and a needle shape. The distribution of these crystallites in mammoth ivory is shown in the transmission electron micrograph (Fig. 2).

The changes of mammoth ivory are accompanied by recrystallization of carbonate hydroxyapatite. Fossil bones and dentin have better crystallinity than recent specimen [6]. The aim of the present paper is to investigate the structural changes of mammoth ivory, particularly the average sizes of the carbonate hydroxyapatite crystallites in the three different commercial qualities of mammoth ivory, mentioned above, by X-ray powder diffraction (Rietveld method) and Fourier Transform Infrared spectroscopy (FTIR). Furthermore the relative retention of organic components from the collagen and the incorporation of carbonate relative to the phosphate in the carbonate hydroxyapatite structure were determined in the samples under study.

Figure 1
A broche made of mammoth ivory

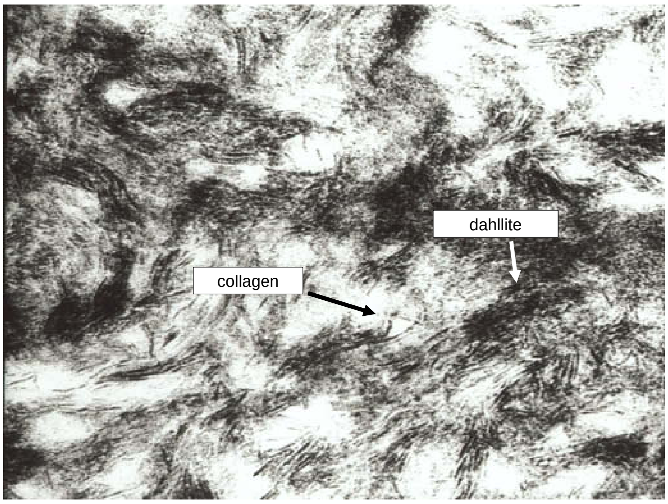


Figure 2
TEM microphotograph (magnification 31500X) of mammoth ivory showing needles of carbonate hydroxyapatite (dark colour) in a collagen matrix (white areas).

2 Materials and Methods

Altogether seven samples of mammoth ivory from the collection of **In**ternational **Cent**er of **I**vory **S**tudies (INCENTIVS) were investigated in this study. The selected samples were of different weathering stages and they represented the three qualities A, B and C as mentioned before (Table 1). All of them were of Siberian origin. The samples were investigated by the following methods:

1. X-ray powder diffraction - Rietveld method
2. Fourier-Transform-Infrared (FTIR) – spectroscopy.

X-ray powder diffraction (XPD) and the Rietveld method [7] are widely recognized to be extremely valuable for structural analyses of nearly all classes of crystalline materials not available as single crystals. The method has been traditionally used for phase identification and crystallographic characterisation, quantitative analysis, microstructure determination and recently also for the crystal structures solution. The phase microstructure characteristics, such as structure imperfections (strains) and the small size of crystallites, cause a broadening of the XPD diffraction-line profiles. As the carbonated bio apatite is poorly crystallized, the Rietveld method was a logical choice of investigation.

The XPD data collection was performed by SEIFERT XRD 3000TT diffractometer with secondary graphite monochromator and CuKα radiation. Samples were powdered in mortar and scanned in a step of 0.03° 2θ within the range of 4-90° 2θ in 10 sec/step.

FTIR deals with the interaction of infrared light with the organic and inorganic compounds [8]. As such the two components of ivory, collagen and carbonate hydroxyapatite, can be investigated by this method.

The FTIR data were obtained by means of Perkin Elmer FT-IR Spectrometer 1725X. Transmission FTIR spectra of different samples of mammoth ivory were obtained using their powders by potassium-bromide-pellet technique. Crystallinity of carbonate hydroxyapatite of different mammoth samples was obtained by calculating the Splitting Factor (SF) from their FTIR spectra (Figures 3 and 4). Carbonate contents of mammoth ivory samples were obtained from their FTIR-spectra according to [9].

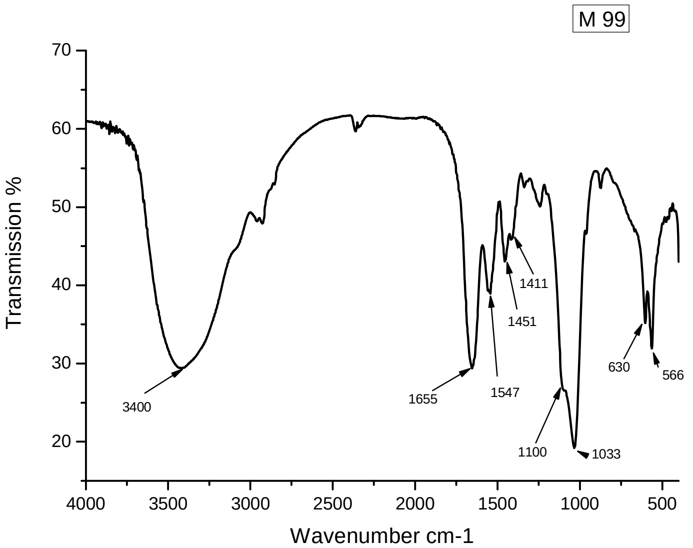


Figure 3
FTIR Spectrum of a sample of a slightly weathered sample of mammoth ivory

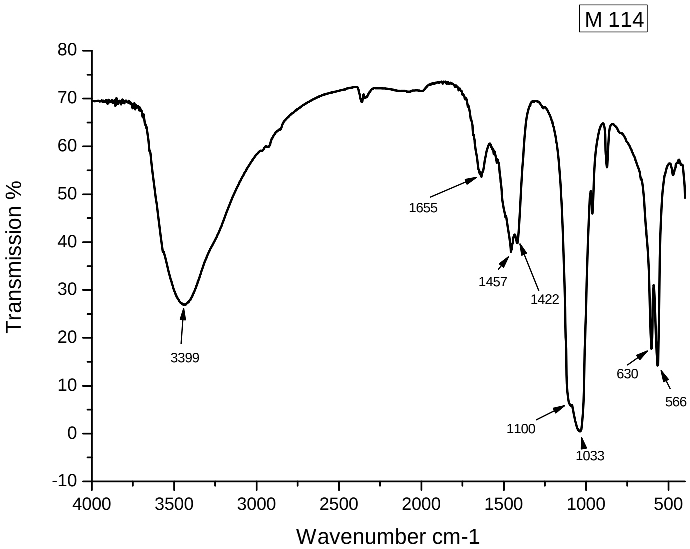


Figure 4
FTIR Spectrum of a sample of an extremely weathered sample of mammoth ivory

Table 1 - Samples description

Sample/Color	Conservation state	Quality
M 36 / white	Unweathered	A
M 123 / white	Unweathered	A
M 124 / yellow	Slightly weathered	B
M 99 / yellow	Slightly weathered	B
M 19 / yellow	Slightly weathered	B
M 114 / braun	Extremely weathered	C
M 101 / braun	Extremely weathered	C

3 Results

3.1 Rietveld investigation

The results of the diffractometric analyses refined by means of the Rietveld method are graphically presented in figures 5, 6 and 7 and Table 2.

All the investigated mammoth samples contain peaks of only one phase, poorly crystallized apatite. The broadened reflections in measured angular range with calculated pattern and difference plot are shown in figure 5. The cause of the peak broadening can be found in the results of microstructural analysis (table 2).

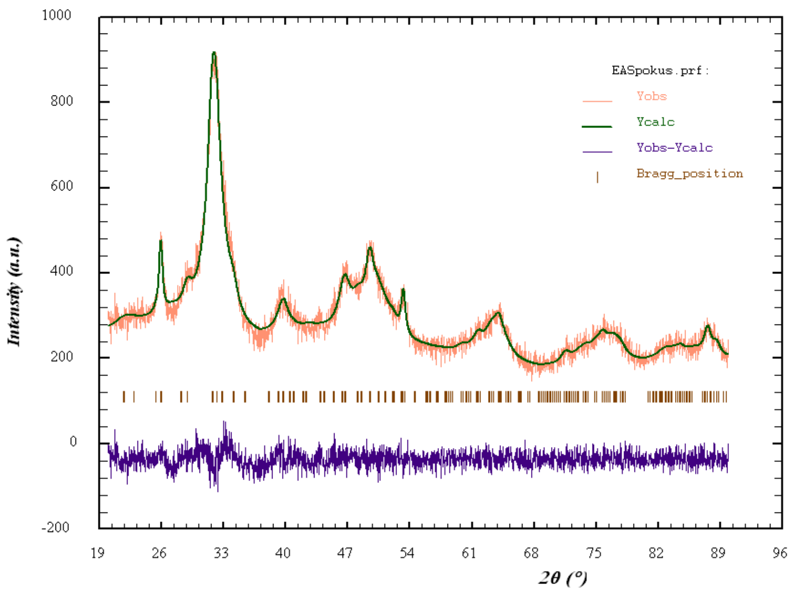


Figure 5
Comparison of calculated (dark) and observed (light) patterns of ivory sample M36. The difference pattern appears below. The vertical bars (bottom) indicate the positions of the peaks.

Table 2 - Calculated crystallite sizes (*D*) and average maximum strain (ε)

Sample	D_{00l} (Å)	$D_{hk0\ (max)}$ (Å)	$D_{hk0\ (min)}$ (Å)	Average D (Å)*	Average ε $\times 10^{4}$*
M 19	150	43	31	54(26)	36(2)
M 36	165	49	35	54(50)	42(5)
M 99	219	51	45	71(36)	54(8)
M 123	169	63	36	67(59)	41(16)
M 124	235	78	37	81(50)	41(6)
M 101	370	95	72	123(71)	25(3)
M 114	300	88	65	113(56)	35(6)

* Standard deviations are calculated using the different reciprocal lattice directions and are thus a measure of the degree of anisotropy, not of the estimated error

The results of the micro structural analysis (table 2) also point out the shape of apatite crystallites. It is apparent that they have larger dimensions (3-5 times) in the *00l* than in the *hk0* direction. Figure 6, created by the GFOURIER program [10], allows a clear visualization.

Moreover, it is possible to recognize three degrees of the conservation state of samples by their crystallite size (table 2, figure 6). With an increasing decay one can see a clear increase in the length (direction *00l*) of the apatite crystallites. The average crystallite size has the same dependence, though in a smaller extent.
the

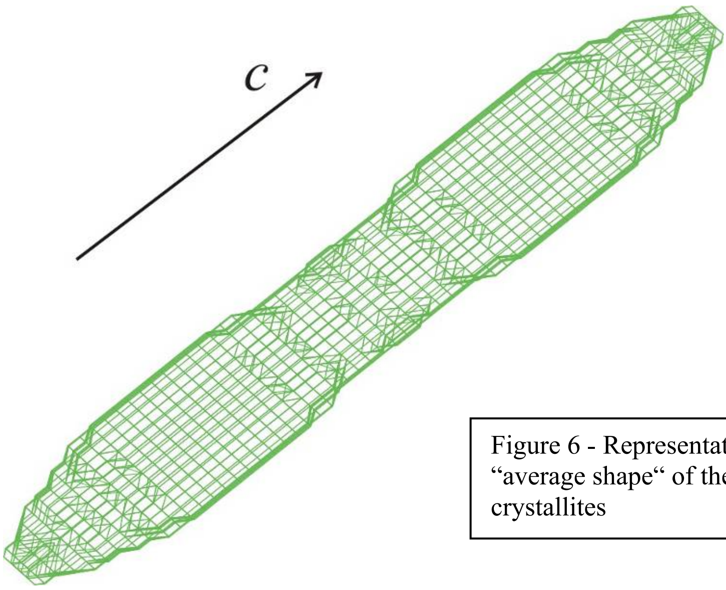


Figure 6 - Representation of the "average shape" of the bio apatite crystallites

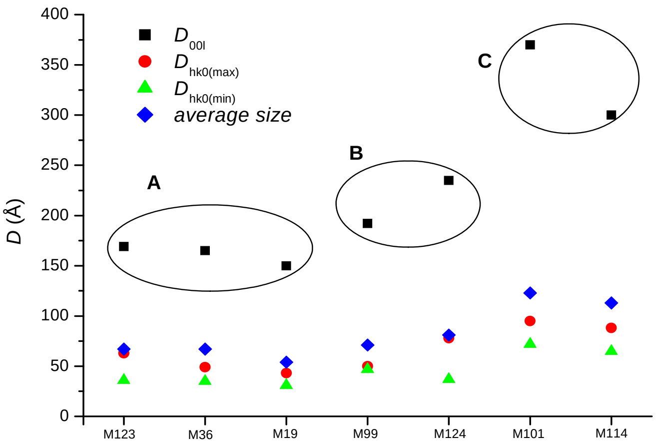


Figure 6 - Average crystallite size along [*00l*] and [*hk0*] directions

3.2 FT-IR Investigation

The crystallinity of carbonate hydroxyapatite, the mineral composing mammoth ivory, can be measured by evaluating its splitting factor (SF). SF is based on the increasing separation of the FTIR absorption band at 565 and 605 cm^{-1}.
The relative retention of organic material and the incorporation of carbonate, relative to phosphate were determined by comparing the heights of amide and the phosphate peaks (1640/1035 cm^{-1}) and the carbonate and phosphate ones (1420/1035 cm^{-1}) (Figures 7, 8, 9 and 10, Tables 3 and 4).

3.3 Evaluation of the spectra

The boundary of the valley A, on the upper part of the spectrum is defined by the connecting line of the bands 605 cm^{-1} and 565 cm^{-1} and it can be calculated indirectly as follows. In the first step of the calculation the exact positions of the two bands are taken as absorptions maxima in the region between 612 and 595 cm^{-1} and 570 and 550 cm^{-1} and this portion of the spectrum is copied in an auxiliary spectrum. After calculation of the connecting line with the help of the x-y coordinates of the two peaks, the real ordinate values are replaced by the ordinate values of the auxiliary spectrum. The exact area of the valley A is obtained by subtracting the identical region of the original spectrum from the trapeze area which is obtained by the construction described above.

The calculation of the B area is obtained according to the base line drawn from 662 cm^{-1} and 480 cm^{-1}(M 99) or 481 cm^{-1} (M 114). Due to the fact that the second fixed point for drawing the base line was not exactly the same in all cases a slight error arise in the calculation of the B area. The calculation was made by using an automatic process software (Perkin Elmer).

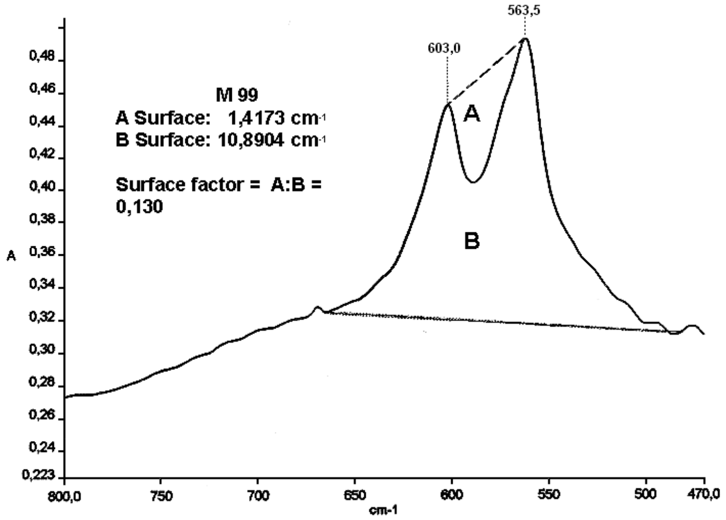


Figure 7 – FTIR Spectrum for the evaluation of the crystallinity on a well preserved sample of mammoth ivory

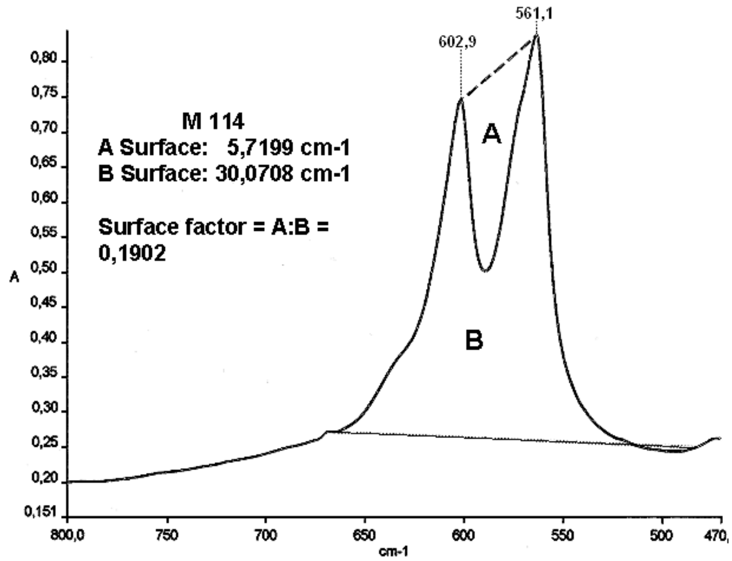


Figure 8 – FTIR Spectrum for the evaluation of the crystallinity on a very weathered sample of mammoth ivory

Table 3 - Crystallinity of the samples

Sample	Splitting Factor SF
M 19	0,136
M 36	0,086
M 99	0,130
M 123	0,089
M 124	0,127
M 101	0,207
M 114	0,190

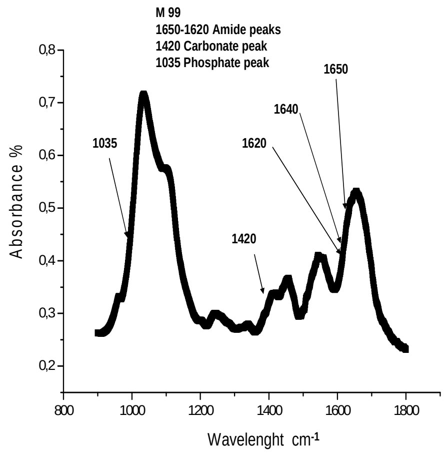


Figure 9 – FTIR Spectrum for the evaluation of the relative retention of organic material and quantity of carbonate in a well preserved sample

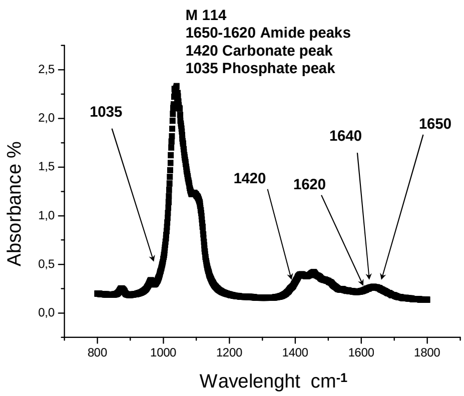


Figure 10 – FTIR Spectrum for the evaluation of the relative retention of organic material and quantity of carbonate in a very weathered sample

Table 4 - Changes of organic and inorganic components of the samples due to degradation		
Sample	**Amide/ Phosphate Ratio 1640/1035**	**Carbonate/ Phosphate Ratio 1420/1035**
M 19	**1,25**	**1,66**
M 36	**1,27**	**1,18**
M 99	**1,48**	**2,30**
M 123	**1,50**	**2,60**
M 124	**7,60**	**12,7**
M 101	**21,75**	**17,75**
M 114	**91**	**66**

4 Discussion and conclusions

From the profile refinement by the Rietveld method, including microstructural characterisation, the following conclusions can be drawn:

- Poor crystallinity of the XRD patterns (Figure 5) was found to be caused mainly by the tiny dimensions of the crystallites. Because the degree of anisotropy by average crystallite size is much bigger than the average maximum strain, i.e. structure imperfections, (Table 2), it can be concluded that the crystallite size is the main reason for the apatite reflection broadening.
- Crystallites show a needle like shape, with the longer axis parallel to the c-axis of the bio apatite hexagonal cell (Figure 6). This conclusion is in agreement with TEM investigation (Figure 1). It should be pointed out that TEM made only the needle like shape of the crystallites visible, but it did not allow to measure their exact dimensions due to the presence of overlapping organic matter.
- The analysis of X-ray data made it possible to estimate the crystallites dimensions. The weathered mammoth samples, especially the extremely weathered ones (category C), can be recognized mainly by longer crystallites, though the average apparent size has the same dependence. According to the literature data [2], this is due to the recrystallization of particles during the *post mortem* alteration. So, the unweathered samples are less then 169 Å in length, the slightly weathered are in range 219-235 Å, and the extremely weathered are larger than 300 Å (Table 2). It should be mentioned that due to the small number of samples these results cannot be generalized.
- The results of X-ray Rietveld investigations are identical to the results of FTIR analysis with only one exception, namely sample M19. This is 150 Å in length, and according to conservation state and FTIR analysis (SF value) should be in category B. The explanation can be that the X-ray investigated part of this sample was in better condition than the rest of the sample.
- According to FTIR analysis a sample of mammoth ivory showing higher SF values contains larger crystallites of carbonate hydroxyapatite. As such the sizes of carbonate hydroxyapatite crystallites in the three different qualities of mammoth

ivory mentioned above are respectively small (A quality), medium (B quality), and large (C quality).

- Another highlight of the FTIR investigation was to show the gradual change of chemical composition of mammoth ivory due to weathering: It was proved that both amid/phosphate ratio and carbonate/phosphate ratio of the samples increase due to weathering. In both cases the values are directly proportional to the stage of degradation of mammoth ivory due to diagenesis.
- It is remarkable that there is a direct correlation between the increment of size of the carbonate hydroxyapatite crystallites of mammoth ivory and the degradation of its collagen content: the average size of the carbonate hydroxyapatite crystallites increases as more and more collagen is lost due to weathering.
- Taken into consideration that unweathered samples are younger than the weathered samples, the result of the present investigation can be used to assess the relative age of a specimen of mammoth ivory.

5 Acknowledgments

We thank Dr. Jürgen Bohl, at the Institute of Neuropathology of the University Clinic in Mainz, for carrying out the TEM analysis.

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Non-destructive investigation of Netsuke, Japanese miniature sculptures, by Micro Raman spectroscopy

A. BANERJEE
INCENTIVS – International Centre of Ivory Studies, Johannes Gutenberg-Universität Mainz

Keywords: Netsuke, Raman Spectroscopy, Schreger lines
Schlagwörter: Netsuke, Raman Spektroskopie, Schreger Linien

Zusammenfassung

Netsuke sind 2 bis 3cm groß. Das Wort bedeutet "Wurzel zum Befestigen/Verbinden". Die kleinen Kunstobjekte dienten im Japan des 17. Jahrhundert einem praktischen Zweck: ein Kästchen (*inro*) an einer Seidenschnur wurde an den Kimonogürtel (*obi*) gehängt. Am Ende dieser Schnur war ein *Netsuke* befestigt, das verhinderte, daß das Kästchen zur Aufbewahrung persönlicher Habe (Tabak, Siegel u.s.w.) verloren gehen konnte. Ursprünglich trugen nur *Samurais* diese kleinen Kunstwerke. Die Mode wurde dann im 18. Jh. von reichen Kaufleuten und Würdenträgern übernommen. Aus den ursprünglich rein nützlichen Gegenständen wurden schließlich äußerst begehrte Sammelobjekte nicht nur in Japan, sondern auch in der heutigen westlichen Welt. Der Wert eines *Netsuke* kann 100 bis 100.000 $ betragen.
Netsuke wurden traditionell aus Holz, vorzugsweise Buchsbaum, geschnitzt, oft aber auch aus Tierknochen. Die Meister verwendeten Elfenbein, das aus Indien oder Afrika importiert werden mußte und folglich sehr teuer war. Auch andere "Elfenbein"-Arten wie z.B. die Taguanuß wurden verarbeitet.

Das internationale Zentrum für Elfenbeinforschung (INCENTIVS) in Mainz betreibt Grundlagenforschung von Elfenbein. Die Forschungsgruppe hat Unersuchungsmethoden erprobt, die es ermöglichen, von Museen und Zollbehörden vorgelegte Kunstobjekte zerstörungsfrei zu begutachten und deren Herkunft eindeutig zu bestimmen. Im vergangenen Jahr übergab die Zollfahndung des Frankfurter Hauptzollamts dem Labor von INCENTIVS 200 z.T. sehr wertvolle *Netsuke,* um feststellen zu lassen, ob diese aus Elefantenelfenbein geschnitzt waren und ob damit gegen das Washingtoner Artenschutzübereinkommen von 1989 verstoßen worden war. Die Skulpturen wurden mit Hilfe der Laser-Raman-Spektroskopie untersucht, ohne dabei beschädigt zu werden.
Die dem INCENTIVS vorgelegten *Netsuke* wurden mikroskopisch und spektroskopisch untersucht. Die unter dem Mikroskop erkennbaren Strukturen lassen die meisten Materialien leicht voneinander unterscheiden. Im Falle von Elefantenelfenbein erkennt man anhand der sogen. "Schregerlinien" nicht nur den Unterschied zwischen Elefanten- und Mammutelfenbein, sondern auch den zwischen afrikanischem und indischem Elfenbein.

Die Laser-Raman-Spektroskopie erlaubt eine vollkommen zerstörungsfreie Untersuchung von Kunstgegenständen. Die Bestrahlung eines Objektes mit Laserlicht ergibt jeweils ein charakteristisches Ramanspektrum, das eine eindeutige Identifizierung des Materials ermöglicht. Die Untersuchung der 200 *Netsuke* ergab, daß die meisten aus Elefantenelfenbein, vor allem afrikanischem Elfenbein, hergestellt worden waren. Einmal mehr erwies sich die Mikro-Raman-Spektroskopie als die geeignete Methode der zerstörungsfreien Untersuchung wertvoller Kunstgegenstände.

1 Introduction

The International Centre of Ivory Studies (INCENTIVS) is engaged in the basic research of ivory. Special spectroscopic methods have been developed by this working group for non-destructive investigation of ivory objects in order to determine the type and source of ivory out of which they are made. Museums and customs departments in Germany regularly send ivory objects to INCENTIVS for investigation, which some times include remarkable interesting objects of art.
Last year, for example, two hundred confiscated Japanese miniature sculptures, netsuke, were sent to the laboratory of INCENTIVS by the customs department of Frankfurt Airport for investigation. Purpose of investigation was to find out if only some or all of them were made of elephant ivory. As known, according to the CITES (Convention on international trade in endangered species) regulation there is a strict worldwide ban on elephant ivory since 1989. It should be mentioned that Netsuke are very valuable objects, whose commercial value range from 100 US dollars to one hundred thousand US dollars. The value of a netsuke is judged by the quality of carving, originality and the subject.

Obviously due to their high value investigation of all the netsuke had to be done by a non-destructive method. Laser Raman spectroscopy, which is a non-destructive tool, was used for the investigation of the netsuke.

2 Netsuke

Netsuke are artistic miniature belt ornament of Japanese Kimono for me. The average size of a Netsuke varies from 2 to 8 cm. In Kanji character "ne" means "root" and the second character "tsuke", from the verb "tsukeru" meaning "to attach or connect". As such the Japanese meaning of the word Netsuke is "root for fastening". Originally Netsuke was a utilitarian object in Japan in the seventeenth century. As the Japanese Kimono had no pockets, men had to find a method to carry small belongings like tobacco, seals and other personal belongings. Men would wear a silk cord on their ***obi*** or belt of their kimono. From the cord they used to hang their personal belongings in a box, called ***inro***. In order to stop the silk cord from slipping under the weight of the inro, people attached a small toggle, a ***netsuke***, at the cord of the inro. A netsuke has two holes to form a channel, called

himotoshi, through which the silk cord of the inro is passed in order to hold it in place.
Originally Kimonos of Samurais were equipped with netsuke but latter in the beginning of the 18th century also rich merchants and other dignitaries began to wear a Netsuke on their Kimono. Usually Japanese men used to have not only one, but several netsuke of different shapes and motifs.
Earlier netsuke were purely utilitarian, but gradually they were considered as highly appreciated artistic sculptures. Today they have become coveted collectors item in Japan itself and also in the western world.
Netsuke are of different shapes and display a large variety of motifs. Each and every Netsuke tells a story of its own. Value of a netsuke depends on the artist, region and the craftsmanship of the artist. Netsuke are cut skilfully to create figures which display various aspects of Japanese culture. The fascination of netsuke is their originality. Some are humorous, some whimsical, some clever, but all seem completely self-contained stories, unique interpretations by skilled artists.

2.1 Shapes and motifs of netsuke

Netsuke are of different shapes and display a large variety of motifs.

The main shapes of netsuke are:

- Kataburi: the normal compact form of netsuke
- Sashi: a long and thin netsuke
- Kagamibatu: a netsuke in the form of a bowl with a metal lid on top
- Manju: a round and flat netsuke that resembles a button

The usual motifs of netsuke can be classified as follows:

- Chinese and Japanese immortals
- Buddhist figures
- Popular religious figures: the seven gods of good luck)
- Figures from Japanese literature
- Figures from everyday life: typical occupations
- Mythological animals
- Common animals: monkeys, horses, oxen, goat, boars, cats, dogs, rats, snakes, fish etc.
- Fruits, vegetables and flowers: pear, mushroom, pumpkin, eggplant, rose etc.
- and masks.

Some netsuke under investigation are shown (Fig. 1).

Figure 1 - Some netsuke under investigation

2.2 Materials used for netsuke

Traditionally wood, preferably boxwood is the most common material for netsuke. The second common material for netsuke is animal bone. However due to its attractive appearance elephant ivory has been used as a most valuable working material by master craftsmen for netsuke. Earlier elephant ivory was a very costly material in Japan, as it had to be imported from India or Africa. It was mostly used making plectrum for the Japanese string instrument, the samisen. Netsukes were made from the left over, for example, the tip of the tusk.

Besides typical ivory, the tusk of elephant, there are also other types of ivory, for example, mammoth ivory, walrus ivory and sperm whale ivory. Another material, which is commonly used for netsuke is the tagua nut. This nut, also known as vegetable ivory, is often mistaken for elephant ivory. It comes from the tagua palm (*Phytelephas macrocarpa*) found in tropical rain forests in South American countries, for example in Peru, where it has been used for a very long time as a substitute for ivory.

Moreover, there are also other materials like resins, antlers, horn, tortoise shell, which are used for netsuke.

3 Method of investigation

3.1 Optical microscopy

Netsuke made of materials like wood, ceramic, tortoise shell and resins can be easily recognised under the microscope. Two materials, e.g. bone and tagua nut look very similar to ivory. Netsuke made of bone can be recognised by the black spots, the typical “dots and dashes” on their surface. Netsuke, made of tagua nuts on the other hand show circular “tree rings” on their surface. However the different types of mammalian ivory, as for example, Hippo ivory, walrus ivory and sperm whale ivory are difficult to distinguish from one another. Hippo ivory has a tight grain and a dark vein or split in it. Elephant and mammoth ivory can be identified visually and also under the microscope according to the Schreger pattern, a typical cross hatching, called Schreger pattern. This pattern is typical only for these two types of ivory. This pattern occurs due to the three dimensional arrangement of dentine tubules in dentine of elephants and mammoth.
Schreger pattern, named after Schreger, is composed of two intersecting systems of curved lines. The intersecting Schreger lines form different angles in different types of elephant ivory for example, for ivory of African elephants the value of Schreger angle is 118 degree, for ivory of Indian elephant the Schreger angle it is 123 degree and for mammoth ivory the Schreger angle is less than 90 degree. According to such measurements it was found that some netsuke were made of different types of elephant ivory and some of them were made of mammoth ivory. Identification of ivory by measuring the Schreger angle was difficult or rather impossible in cases where the Schreger pattern was not visible on the surface of the netsuke. This is the case when a netsuke is painted with a colour. In such cases Laser Raman spectroscopy was applied for the investigation.

3.2 Micro Raman spectroscopy

It is a non-destructive technique, which do not need any sample preparation. It is named after its inventor Sir C. V. Raman. Its working principle involves in illuminating a sample with light and using a spectrometer to examine light scattered by the sample. A laser is used as a source of incident photons that gain or lose energy when they interact with molecules in a sample, producing frequency shift in the scattered photons. The frequency shift, the Raman shift, corresponds to the energy difference between the incident and scattered photons. Different materials have different vibration modes and therefore characteristic Raman spectrum. Raman spectra of the netsuke under investigation in the region between 500 and 2000 cm-1 were obtained with a confocal laser Raman system HR 800 (Jobin Yvon). The Raman spectrometer was equipped with a confocal microscope (Fig.2) Exciting radiation was provided by a Helium- Neon laser (Lambda = 632.817 nm). Materials used for the netsuke were identified according to their typical Raman spectra (Fig. 3).

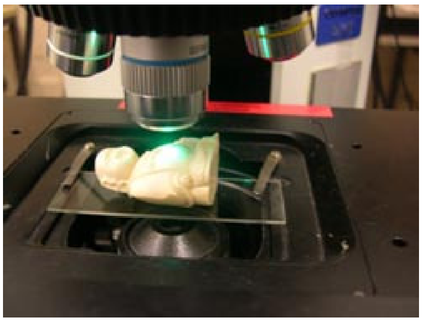

Fig. 2 - Non- destructive investigation of netsuke by Laser Raman Spectroscope equipped with a confocal microscope

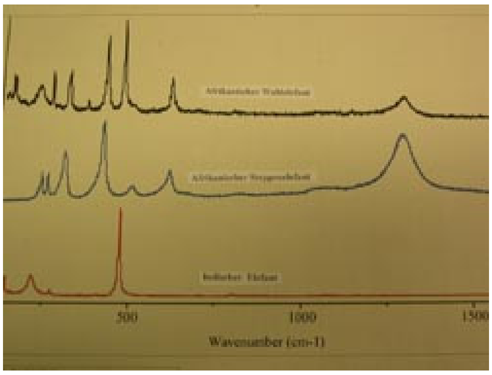

Fig. 3 - Raman spectra of 3 types of elephant ivory

4 Results and conclusion

According to the present investigation materials used for the 200 netsuke under investigation are as follows:

Elephant ivory from Africa	= 75 netsuke
Elephant ivory from India	= 31 netsuke
Mammoth ivory	= 38 netsuke
Animal bone	= 23 netsuke
Wood	= 11 netsuke
Tagua nut	= 17 netsuke
Resin	= 2 netsuke
Ceramic	= 1 netsuke
Antler	= 2 netsuke

It is concluded that Laser Raman spectroscopy is a most suitable non-destructive tool for material testing of valuable objects of art like netsuke. Even the original material of netsuke, which were painted on their surfaces could be identified by the application of the confocal microscope attached with the Raman spectrometer.

5 References

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African or Asian? DNA Analysis of Byzantine and Western Medieval Ivories

A. CUTLER and A. GÖTHERSTRÖM
Pennsylvania State University and Uppsala University

Keywords: DNA Methods, Byzantine ivory, provenance of ivory
Schlagwörter: DNA-Methoden, Byzantinisches Elfenbein, Herkunft von Elfenbein

Zusammenfassung

Zu den zahlreichen Schwierigkeiten, die mit der Untersuchung mittelalterlicher Elfenbeinschnitzereien verbunden sind, gehört das Problem der Herkunftsbestimmung des Materials, das die Kunsthandwerker in den Hauptproduktionszentren benutzten. Diese Fragestellung ist von besonderem Interesse im Falle von Byzanz im 10. und 11. Jahrhundert und von Frankreich im 13. und 14. Jahrhundert - Stätten und Zeiträume, in denen Kunstwerke aus Elfenbein entstanden sind, welche von Kunsthistorikern höchst geschätzt und in Museen und Privatsammlungen als Schätze gehütet werden.
Das folgende Referat erläutert Methoden und Schlußfolgerungen einer Studie, welche den Mitochondrialen DNA-Gehalt von (a) einem Fragment eines byzantinischen Triptychonflügels - jetzt Teil einer Sammlung in Innsbruck - und (b) einer französischen oder italienischen Statuette vom Metropolitan Museum of Art in New York untersucht. Im ersten Fall kann ein afrikanischer Stoßzahn (Loxodonta africanus/Loxodonta cyclotis) als Ausgangsmaterial nachgewiesen werden,im zweiten Fall wurde ein asiatisches Exemplar (Elephas maximus) bearbeitet. Die ausführliche Veröffentlichung der Untersuchung wird die angewandten Analysetechniken darstellen, so dass diese bei anderen Objekten Anwendung finden können. Zunächst möge es genügen anzumerken, daß die Methode zur Unterscheidung von afrikanischem und asiatischem Elfenbein bei historischen Objekten zur Verfügung steht, auch wenn solche Untersuchungen die Zerstörung von Proben erfordern und deshalb bei Museumsgegenständen kaum Anwendung in größerem Umfang finden werden.

Introduction and Discussion

Although many suggestions, mostly impressionistic and dating from an era when ivory was widely worked by craftsmen,[i] have been made as to the way in which “fresh” African elephant ivory may be differentiated from Asian materials, till now the only means of distinguishing between historical objects carved from these substances had been the rule of thumb that artefacts involving panels or other sections wider than 11 cm must come from elephants of African origin.[ii] Based upon a series of measurements empirically derived from specimens in museums of natural history (and obtained by the simple calculation of a tusk’s maximum diameter from its circumference), this “law” has on occasion been challenged,[iii] but is for the most part accepted by historians interested in the source of the material that gave rise to the objects with which they are concerned.[iv]

A much more precise method, if, on the face of it, one only indirectly related to our objective, appeared in 2005 in a study that showed how to discriminate between ivory from the woolly mammoth and that of its genetic kin the Asian elephant, which is more closely related than the African species to its Pleistocene forebears. This distinction was achieved through the amplification and analysis of the mammoth's mitochondrial DNA in a series of tests undertaken in Germany, the UK, and the USA.[v] The paper that follows will describe a similar experiment, – one more directly addressed to medievalists interested not only in the age of ivory involved but also in its geographical origin and thus, by implication, of concern to historians of trade and broader patterns of intercourse in the medieval world. We shall outline the method used in, and the results of, an analysis conducted in Gothenburg, Sweden, aimed at distinguishing African from Asian material in two medieval objects.

Before turning to the science, it will be useful to put these objects in their historical setting. The first is a large portion of a Byzantine triptych wing to be dated in the 10th or 11th century and now in a private collection in Innsbruck.[vi] This preserved portion measures 7.1 x 6.3 cm. The obverse of the plaque shows the waist-length figure of St Paul[vii] holding a book (Fig. 1) and turning toward the now-lost central member of the triptych which, to judge from analogous surviving examples, could have been the Virgin and Child, the Crucifixion, or some other sacred and standard MiddleByzantine image.

Fig. 1 and 2 - Innsbruck, private collection. Triptych wing, obverse (left), reverse (right)

The presence of the frame at the top shows that the saint was the uppermost figure on the wing, on the reverse of which was carved a no less conventional cross, tapering toward its centre and adorned with pellets at its extremities (Fig. 2). The fragment subjected to DNA analysis came from the area that has broken just below the top left corner of the reverse.

Even had its full width (which we may estimate to have been about 6.6 cm) been preserved, the 11 cm rule would not have served to determine the origin of the ivory. And as much is true of the second object tested, the very desiccated figure of an apostle which, since 1917, has belonged to the Metropolitan Museum of Art in New York (Fig.3).

Fig. 3 and 4 - New York, Metropolitan Museum. Apostle, general view (left) and view of underside (right)

This is a late-13th-century work carved either in France or Italy,[viii] an impressive 27.8 cm high. For our present purposes, it is the diameter of the pedestal that is of interest: from the original dowel hole in this base came the sample that we subjected to analysis. Representing the diameter of the tusk at almost its widest extent, at 7.75 cm the statuette still remains too narrow for the origin of its material to be determined by the 11 cm rule. In both instances, then, a test independent of the size of the artefacts is necessary. This is available in the genetic forms of ivory which allow the allele frequencies of samples of their DNA to be measured and compared with data already in the on-line genebank. (An allele is one of two or more forms of a gene that exists at a single locus. When such a site has two or more forms it is said to be polymorphic). Allele frequencies have been tested in various sub-species of fresh African ivory in an operation deliberately designed to help combat the illegal trade in that substance.[ix] But since our objective, to distinguish African from Asian ivory, was different we tested their haplotypes – different combinations of polymorphisms. The final result was, as we shall see, productive. Yet Asian elephants present a problem in this respect for one is forced to rely on only the ten sequences (as of 2006) in the genebank, [x] several of which come from Far Eastern sources and represent only the distribution of *Elephas maximus* today.

Given that the Asian reference material is limited, one might come upon a sequence of polymorphisms that is certainly not African but is as yet unrecognized as Asian. Secondly, whether Asian or African ivory is involved, it must be remembered that tusks are enlarged maxillary incisors, consisting primarily of dentine deposited by odonblastic cells; for this reason there is no cellular structure in the tusk to provide genetic material. However, as was suggested as long ago as 1998, remnants of these cells are to be found there in dentinal tubules.[xi] This was confirmed by an initial experiment in 2003.[xii] But given that DNA is heavily fragmented[xiii] and subject to degradation over time,[xiv] the tests that can be done on modern ivory are not easily reproduced in the case of historic material.

Our understanding of the genetics of Indian elephants in historical times is, therefore, rather meagre. Even so, the quality of the African sample, together with the nature of polymorphic base substitutions – the same polymorphism is rarely found in two different species which either have their own polymorphisms or are polymorphic in one species but not the other – makes it possible to identify them as coming from African or "non-African" elephants, in which case non-African material means that it is Asian.

Of our two ivory samples, the first showed a combination of the four polymorphic sites that are known only in modern African elephants. The second harboured a different combination found only in Asian elephants. In the following description of our procedure, addressed primarily to biophysicists, we shall insert glosses on our successive steps in an attempt to make them more comprehensible to those who are not scientists. At the end we shall return to the historical implications of our findings.
We retrieved results from four polymorphic sites, that varied between African (*Loxodonta africana*) and Asian elephants (*Elephas maximus*), in the mitochondrial gene cytochrome b.[xv] Of the four polymorphic sites addressed, at least two were polymorphic within one of the two species (but seemingly fixed in the other). The other two sites seemed to be fixed in both types of extant elephants. With this data it was possible to assign each sample to either the African or Asian creature. One problem with this way of identifying the type of elephant is that we are relying on modern animals (genebank sequences) to describe historical populations. This may be less problematic in the case of African elephants, where the size of modern samples is large and the only concern is that most haplotypes should be preserved over moderate periods of time.

To counter the problem of applying to historical material information obtained from modern ivory, we used an approach based on selectively extracted and purified DNA fragments, extremely short PCR (polymerase chain reaction) products, and pyrosequencing.[xvi] The extraction and purification were carried out in two steps, following the stringent criteria recommended for ancient DNA research.[xvii] First, DNA was extracted from the ivory samples with a phosphate buffer. The phosphate competes with the DNA for adsorption to the minerals in ivory, and the DNA is released in the solution. Thereafter, the relevant DNA fragments were selected and fished out with hybridization and magnetic separation. This was used as template DNA in a PCR targeting short fragments (<60 bp including primer sites).

As mentioned above, there is a risk that genetic diversity has been lost in both species and that we have an insufficient sample from modern *Elephas maximus*. However, as the haplotypes that we observed in our samples – constituted by the four polymorphic sites that today separate the two species – exist in extant elephants, it is hard to imagine a scenario in which these different types were present in both species of elephant. We therefore conclude that our first sample, derived from the triptych wing, represents African ivory, and the second, from the Apostle statuette, came from Asian material.

We thus have a diagnostic method more finely tuned than Fourier Transform Infrared Spectroscopy (FTIR) and Raman spectroscopy to the problem of discriminating between African and Asian ivory.[xviii] While FTIR and Raman spectroscopy are non-destructive, they better serve the broad purpose of distinguishing, for example, mammoth and walrus ivory from the dentine of both species of elephant. By contrast, the tests on DNA that we have described are destructive and therefore unlikely to be widely applied to artefacts of historical and aesthetic importance. The promise that the distinction between African and Asian ivory holds for the study of medieval trade routes is often celebrated. Particularly in light of the fact that Indian material, at least until the 6th century,[xix] travelled across the Indian ocean to East African ports before being shipped on via the Red Sea to Egyptian *entrepôts*, along with tusks from the lands that are now Uganda, Rwanda, and Burundi,[xx] it is helpful to be able to distinguish the various sources of ivory. The distinction will be no less useful if it can be shown that Asian ivory continued to reach East Africa, the coast of which was under Mamluk control at the time the Metropolitan's statuette was carved. It was possibly via this route that Asian ivory reached Italy and France. Be that as it may, we now have the means to identify the origin of the material in question.

It is obviously risky to hazard generalisations on the basis of a single sample of African and a single sample of Asian ivory. Yet such scepticism can be met, at least in part, with a final, art historical observation. The New York Apostle was most likely one of twelve, a grouping that suggests it was the product of a professional workshop. As to the triptych wing, while the existence of large-scale workshops in Constantinople has been questioned,[xxi] there is no doubt that in its form, carving technique, and iconography, it is closely related to a sizeable number of other pieces, a body of resemblance that implies the broad availability in Byzantium of supplies of African ivory.

Notes and Bibliography

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[ii] A. CUTLER (Washington, D.C. 1985); *The Craft of Ivory* 27-29.

[iii] F. VON BARGEN (1994); “Zur Materialkunde und Form spätantiker Elfenbeinpyxiden,” *Jahrbuch für Antike und Christentum* 37, 56-57, drawing her information from Rowland Ward’s *Records of Big Game, Africa and Asia* (San Antonio 1989), recalled the size of the tusk of an Indian elephant killed by King George VI. In response, A. Cutler, “Of First Principles and Second Thoughts” in his *Late Antique and Byzantine Ivory Carving* (Aldershot 1998), 4, observed the lack of dependability inherent in the genre of sporting records, especially when associated with royal personages.

[iv] See, e.g., L. Nees (2006); “Charlemagne’s Elephant,” *Quintana* 5, 13-49, esp. 39.

[v] J. KRAUSE ET AL. (18 December 2005); “Multiplex amplification of the mammoth mitochondrial genome and the evolution of Elephantidae,” http://www.nature.com/nature/journal/v439/n7077/full/nature04432.html.

[vi] H. SCHNITZLER ET AL. (1965); *Mittelalterliche Kunst der Sammlung Kofler-Truniger, Luzern (= Aachener Kunstblätter,* 31), 13, no. 512. We are indebted to the present owner for permission to study and photograph the object.

[vii] The presence of the inscription identifying the figure differentiates the plaque from other surviving triptych wings. For comparanda see A. Goldschmidt and K. Weitzmann, *Die byzantinischen Elfenbeinskulpturen des X. – XIII. Jahrhunderts. II, Reliefs* (Berlin 1934, reprint Berlin 1979), nos. 130, 131, 155, 183-186.

[viii] This is the view of Charles Little, its curator, to whom we are grateful for permission to study the object, inv. no. 17.190.196. It remains unpublished, but for closely related objects see C.T. Little, “L’art de l’ivoire au temps de Philippe le Bel: renouveau et tradition” in *1300…L’art du temps de Philippe le Bel. Actes du Colloque International, Galeries nationales du Grand Palais 24 et 25 juin 1998*, eds. D. Gaborit-Chopin and F. Avril (Paris 2001), 75-88. Our photographs were made by Thomas Vinton of the Medieval Department at the Metropolitan Museum.

[ix] S.K. WASSER ET AL. (12 October 2004);“Assigning African elephant DNA to geographic region of origin: Applications to the ivory trade,” *PNAS* 101, no. 41 14847-14852.

[x] http://www.ncbi.nlm.nih.gov/Genbank/index.html, which, as of January 2006, contained 10 Asian elephant sequences.

[xi] RAUBENHEIMER ET AL. (1998); “Histogenesis of the chequered patterns of ivory of the African elephant (*Loxodonta africana*),” *Archives of Oral Biology* 43, 12, 969-977.

[xii] K.E. COMSTOCK ET AL. (Dec. 2003); “Amplifying Nuclear and Mitochondrial DNA from African Elephant Ivory: a Tool for Monitoring the Ivory Trade,” *Conservation Biology* 17, 6, 1840-1843.

[xiii] M. HOFREITER ET AL. (2001); Ancient DNA,” *Nature Reviews Genetics* 2, 353-354.

[xiv] C. I. SMITH ET AL., (2003);“The thermal history of human fossils and the likelihood of successful DNA amplification,” *Journal of Human Evolution* 45, 203-217;
S. PÄÄBO ET AL. (2004); “Genetic analyses from ancient DNA,” *Annual Review of Genetics* 38, 645-679.

[xv] Forty-eight complete or almost complete elephant *cytochrome b* sequences (8 *Elephas maximus*, 2 *Mammuthus primigenius*, and 38 *Loxodonta africanus* / *Loxodonta cyclotis*) were downloaded from the genebank. Sequences were aligned using Sequencer 4.1.2. 4 polymorphic sites were selected (162, 165, 171, and 402) and amplified in two fragments (165/171F: 5'CAGGATTATTCCTAGCCATA3' and 165/171R 5'biotin-GATGAAAATGCAGTTATTGTG3' for a 55bp fragment, and 402F: 5'CTTCATAGGATATGTCCTTC3' and 402R: 5'biotin-CTCAGAATGATATTTGTCCTC3' for a 44bp fragment).

The surfaces of the ivory piece were brushed and UV-irradiated with 0.5 J/cm^2 at 254 nm on each side and thereafter wiped clean with 1 M HCl, ddH^{2}O and finally with 95% ethanol. Before drilling, a layer of approximately 1 mm was removed from the sample surface by grinding using a drill. Two samples with approximately 70 mg of powder were prepared with a drill from each specimen. The powder was collected onto foil and transferred into 2 ml polypropylene micro tubes. DNA was extracted using hybridisation and magnetic bead separation after releasing the DNA from the apatite complex. See A. Götherström et al., "Cattle domestication in the Near East was followed by hybridization with aurochs bulls in Europe," *Proceedings of the Royal Society, Biological Sciences* 272 (2005), 2345-2350.

[xvi] On this five-step process see http://en.wikipedia.org/wiki/Pyrosequencing. Pyrosequencing was used to type the four polymorphic sites. Successfully amplified biotinylated PCR products were immobilised with streptavidin-coated Sepharose™ beads for strand separation of DNA template. Sequencing primers were added (165/171PyroF: 5'GGATTATTCCTAGCCATACA3' and 402PyroF: 5'TCATAGGATATGTCCTTCC3') according to Pyrosequencing PSQ™ Sample Preparation Guidelines for SNP analyses (Biotage). The SNP pyrosequencing reagent kit (dATPαS, dCTP, dGTP, dTTp, enzyme and substrate mixtures) was used according to manufacturer´s instructions (Biotage) and analyses were performed on a PSQ 96 MA instrument using the SNP software system. Data were presented as pyrograms (see Fig.A). The complete process has been described in detail elsewhere (Götherström et al., in press).

Authentication of the results is a key aspect in analyses of ancient DNA. Here several recommended criteria for stringent ancient DNA research were used (A. Cooper and H. N. Poinar, "Ancient DNA: do it right or not at all," *Science* 289 [2000], 1139). Thus, all samples were extracted at least twice, and each fragment was twice amplified from each extract, giving a minimum of 4 amplification / accepted results. All work was carried out in a laboratory where there had never been any work on elephant DNA. Common measures to prevent contamination were used, such as a separated area for working with pre-PCR and ancient DNA, the wearing of protective clothing, UV-sterilisation of all reagents, and cleaning of all working surfaces and tools with HCl and sodium hypochlorite. Primers were designed in a way so that they would not anneal to human DNA, and this was verified by amplification.

Both fragments, 165/172 and 402, could be repeatedly amplified from both samples. Pyrosequencing proved to be a reliable way to determine base composition. Sample A possessed substitutions known only from African elephants (Lox*odonta* *africanus / Loxodonta cyclotis*) in the extant fauna (162=T, 165=T, 171=T, and 402=T), while sample B (from the Apostle statuette) possessed substitutions known only from Asian elephants (*Elephas maximus* 162=T, 165=C, 171=T, 402=C).

32 negative extraction controls were used in the study. 16 consisted of ddH^2O and 16 consisted of ancient bear samples, to which none of the primers should anneal. None of these contained amplicons after PCR. Yet another 16 negative PCR controls were used, also without amplifying any DNA.

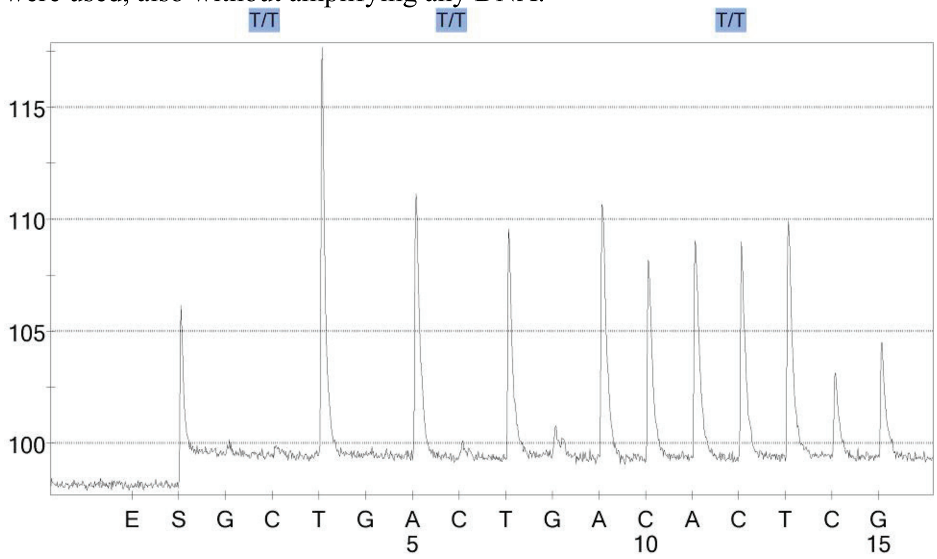

Figure A. Example of pyrogram from sample A, detecting the bases in 162 (T), 165 (T), and 171 (T). Pyrograms were generally of good quality, and the polymorphic state could usually be detected.

[xvii] COOPER AND POINAR, as in note 16.

[xviii] G.M. EDWARDS HOWELL ET AL.(1998); "Fourier-Transform-Raman Spectroscopy of Ivory: a Non-Destructive Diagnostic Technique," *Studies in Conservation* 43, 9-16. See also A. Banerjee, "Non-destructive Investigation of Ivory by FTIR and Raman Spectroscopy," forthcoming in *Spätantike und byzantinische Elfenbeinwerke im Diskurs*, Internationales Symposion, Staatliche Museen zu Berlin, Skulpturensammlung und Museum für Byzantinische Kunst, 07.-09. März 2002, ed. G. Bühl, A. Cutler and A. Effenberger (Wiesbaden 2007). The use of DNA fingerprinting to distinguish between ivory from subspecies of African elephants was outlined by J. Cherfas, "Science Gives Ivory a Sense of Identity," *Science* 246 (1989), 1120-1121. We hope to consider this distinction more fully in a forthcoming paper.

[xix] CUTLER, *The Craft of Ivory* (as in n. 2), 22.

[xx] H.W. MUTURO (Leicester 1998);"Precolonial Trading Systems of the East African Interior" in *Transformations in Africa. Essays on Africa's Later Past* 186-203.

[xxi] A. CUTLER (Princeton 1994); *The Hand of the Master: Craftsmanship, Ivory, and Society in Byzantium* (9^{th}-11^{th} *Centuries)* 66-71.

High-resolution X-ray tomography imaging of ivory

[1]F. ENZMANN, [1]M. KERSTEN, [2]J. GOEBBELS & [2]D. MEINEL
[1]Geoscience Institute, Gutenberg-University, 55099 Mainz, Germany
[2]Federal Institute for Material Research and Testing (BAM), 12205 Berlin, Germany

Keywords: Ivory, high-resolution X-ray tomography
Schlagwörter: Elfenbein, Hochauflösende Röntgen-Computer-Tomographie

Zusammenfassung

Hochauflösende Röntgen-Computer-Tomographie (HRXCT) ist eine innovative und ideale Untersuchungsmethode zur Charakterisierung von verschiedensten Materialien. Diese zerstörungsfreie Methode produziert Schichtbilder in alle Raumrichtung durch eine Probe. Diese Schichtbilder enthalten Informationen über die Röntgen Energie Schwächung innerhalb des Probenobjektes, welche direkt mit Dichte der Materialien zusammenhängt. Die durch Computer rekonstruierten Schichtbilder werden zu dreidimensionalen Bildern zusammengesetzt, die die relative räumliche Dichteverteilung enthalten. Diese können zur geometrischen Charakterisierung (Verteilung von Phasen) und der Visualisierung verwandt werden. Wir untersuchten einen Waldelefanten-Stoßzahn sowie ein Kunstobjekt aus Elfenbein mit unterschiedlichen räumlichen Auflösungen. Dabei werden mit dieser zerstörungsfreien Methode insbesondere die Wachstumsstrukturen des Elfenbeins sichtbar.

1 Introduction

High-resolution X-ray computed tomography is an actual and ideal technique suited to a wide range of solid material investigations. This non-destructive method produces images that correspond closely to serial sections through a specimen. The images reproduce the variation of X-ray attenuation within objects, which relates closely to the material density. Sectional contiguous images are compiled to create three-dimensional representations of density distributions that can be computed digitally to perform efficiently geometrical characterization and visualization tasks. We investigated an ivory tusk and an ivory art object with different tomographic methods and spatial resolutions. Especially remarkable by this non-destructive method was the characterization of the growth structures of ivory.

2 Materials and Methods

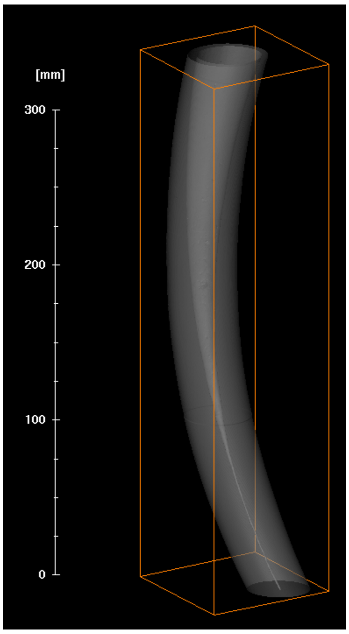

Fig. 1: Half transparency isosurfaces of the upper part of the tusk

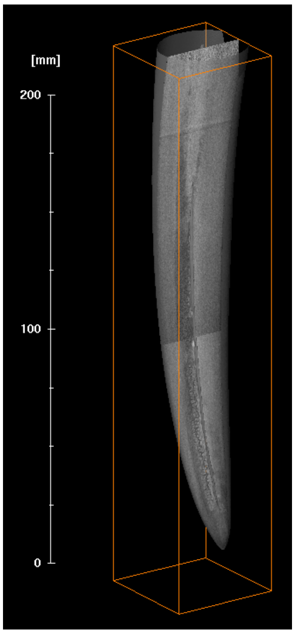

Fig. 2: Lower part of the tusk with a gray scaled slice through the length axis

The first object to investigate was an intact tusk from an African elephant without visible optical structures measuring approximately 60 cm in length and 5 cm in diameter. The tomographic measurements were performed at the BAM in Berlin with an inhouse developed microfocus X-ray tomograph optimized for material research.

The tusk was scanned in multiple stacks because of the object length and the field of view. The resulting voxel datasets were composed by software. Cut planes are visible in Fig. 2. Fig. 1 shows in half transparency mode the surface of the upper part of the tusk. In the lower part, the central hole structure merges to the central nerve, which is visible in Fig. 8, at the top of the tusk. In the middle of the tusk, a gray scale slice is marked, which shows internal structure of the central nerve and the area around.

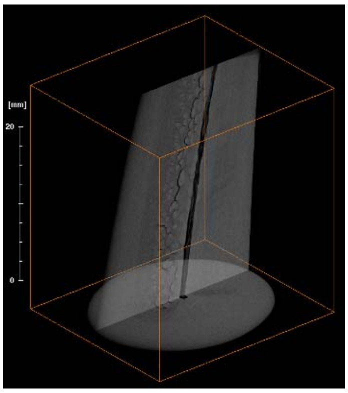

Fig. 3: Half transparency slices through near the top of the tusk, the central nerve is shown

Fig. 4: Contrast enhanced slice near the top

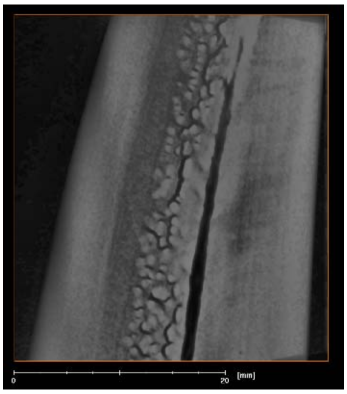

Fig. 5: Special histogram filters makes growth stripes visible in slices

Fig: 6: Same as Fig. 5, slice in opposite direction

The gray scaled slices in Fig. 3-7 represents equivalent CT numbers corresponding to the density of the material [1]. Low density materials such as air or water show a dark colour, while higher density materials are lighter. Minima and maxima of the scaling depend on the scanned material in physical density and thickness (dependence of x-ray absorption). Applying 3D image filters, more details can be shown and segmentation of different material will be possible. Closer to the top of the tusk, a section was scanned with higher resolution of 43 and 21 µm per voxel length, more structural features can be detected. Fig. 3 shows half transparency slices in two areas. The central nerves are visible in dark surrounded by small structured cracks due to withering and shrinking processes in the ivory. This is visible in detail in the contrast enhanced slice of Fig. 4. Combining contrast enhancement and applying a special 3D histogram filter makes growth lines visible. These lines match the age of the elephant and show small density variations during the growth periods [2] The age of the elephant is thus more or less simply deducible from the number of lines [3].

Growth lines are also visible in Fig. 7 together with another interesting structure, i.e. radial lines going from the central nerve towards the surface of the tusk. It has to be noted that the circular structures visible in the lower part of Fig. 7 are the so called ring artifacts coming from small differences in the sensitivity of the detector elements. The final evaluation of these data should be object of a separate paper.

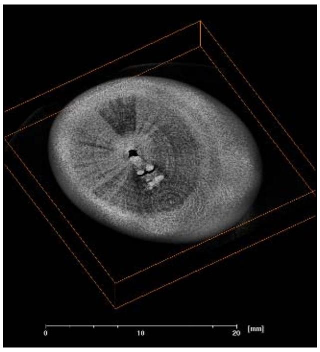

Fig. 7: Perspective view of a group of slices showing ring and radial structures

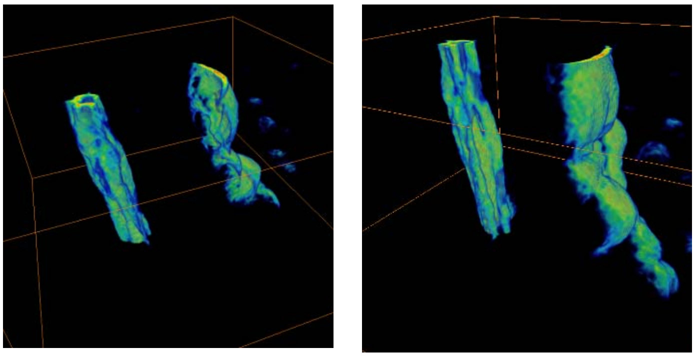

Fig. 8: 3D volume texture visualization of the lower part from the top of the tusk; remarkable is the morphology of the central nerve and the half moon shaped shrinking structures

The second object studied was a so called "airport art" object of ivory approximately 20 cm long and having a mean diameter of 4 cm. Fig. 9 shows the object mounted on the sample holder, ready for XCT procedure.

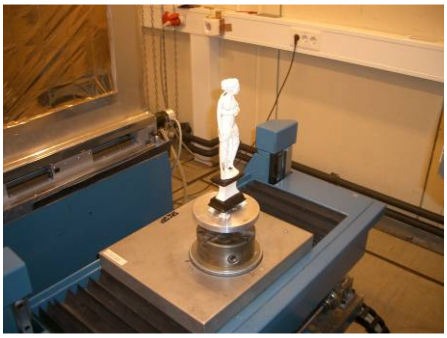

Fig: 9: Ivory object mounted on the sample stage of the XCT machine at BAM, Berlin

The object is centered between the micro focus X-ray source and the flat panel detector shown in the upper left corner of the picture. During the XCT scan, 900 projections rotated over 360° are generated. These projections are the basis for back transformations and building the complete tomogram. The effective voxel resolution for this tomographic data set is 82 µm.

Fig. 10 shows a surface rendering representation of the object based on this XCT dataset. All surface details are visible. Fig. 11 represents slices through the dataset close to the center of the object in two different directions. Fig. 12 shows slices in the opposite direction.

The gray scale (Fig. 11, 12) represents the material density (CT numbers). The growth lines of the tusk (analog to the tusk, first object of this study, e.g. Fig. 5-7) are visible in much more detail. This is a clear proof that this ivory object is made out of an elephant tusk.

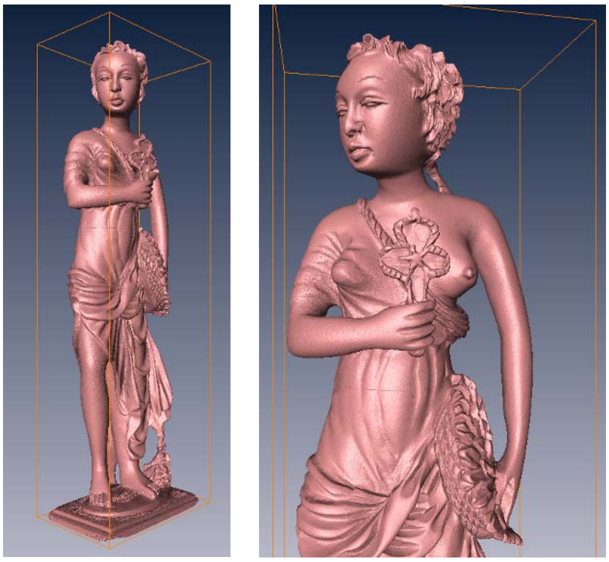

Fig. 10: Surface rendering representation of the ivory object based on the XCT dataset

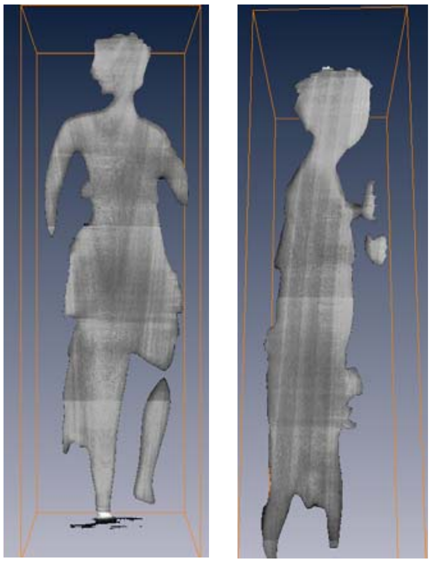

Fig. 11: Slices through the dataset in gray scale, represents material density

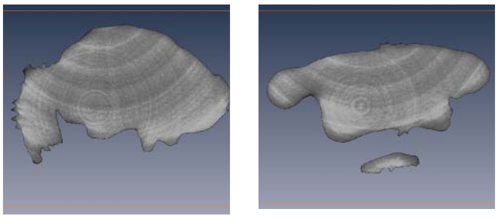

Fig. 12: Slices through the dataset in gray scale, represents material density, opposite direction of Fig. 11

3 Conclusions

The high-resolution X-ray computed tomography technique is suitable to characterize and analyze ivory objects in a non-destructive way. Depending on the object size and spatial resolution of the tomographic data sets, internal structures based on material density variations become visible and enable a more detailed analysis. By means of the µXCT technique used for this study the growth lines of the tusks are visible as well as the structures close to the central nerves. The detailed and final evaluation and analysis of the data is object of a separate paper.

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Neutron Activation Analysis for the Determination of Elements in Ivory

J. HAMPEL[1], A. BANERJEE[2], T. HÄGER[2], G. HAMPEL[1], I. CONEJOS SÁNCHEZ[1],
S. ZAUNER[1]
[1]Johannes Gutenberg-Universität Mainz, Institut für Kernchemie
[2]Johannes Gutenberg-Universität Mainz, Institut für Geowissenschaften

Keywords: Neutron activation analysis, determination of elements, ivory
Schlagwörter: Neutronenaktivierungsanalyse, Elementbestimmung, Elfenbein

Zusammenfassung

Die Neutronenaktivierungsanalyse (NAA) ist eine qualitative und quantitative analytische Technik für die Bestimmung von Elementen sowie Spurenelementen in sehr verschiedenartigen Proben.

Die instrumentelle Neutronenaktivierungsanalyse (INAA), bei der eine chemische Aufarbeitung nicht erforderlich ist, wird für eine Elementanalyse von Mammut- und Elefantenelfenbein genutzt. Die Proben werden am Forschungsreaktor vom Typ TRIGA II im Institut für Kernchemie der Universität Mainz mit Neutronen bestrahlt, wobei die (n,γ)-Reaktion zur Aktivierung stabiler Isotope ausgenutzt wird. Die Bestrahlungen werden bei einer thermischen Reaktorleistung von 100 kW im Bestrahlungskarussell für eine Zeit von 6 Stunden bei einem Fluss von 0,7 x 10^{12} n/(cm² s) sowie mittels des Rohrpostsystems für Kurzzeitbestrahlungen von 10 Minuten bei einem Neutronenfluss von 1,7 x 10^{12} n/(cm² s) durchgeführt. Anschließend werden die Proben gammaspektroskopisch gemessen.

Die derzeitigen Analysen zeigen eine Vielzahl von Elementen, die eine qualitative Aussage zulassen. Für eine quantitative Analyse werden die gemessenen Aktivitäten relativ zu Standards der jeweiligen Nuklide bestimmt. Zusätzlich ist es erforderlich, hierfür ein standardisiertes Probenvorbereitungs- und Messverfahren aufzubauen. Die Verfahren und Ergebnisse werden mit Literaturwerten sowie der Anwendung der INAA an Zähnen verglichen.

Abstract

The neutron activation analysis (NAA) is a qualitative und quantitative analytical technique for the determination of elements and trace elements in a variety of complex sample matrices. The method is applied to an element analysis of mammoth und elephant ivory. The samples are irradiated with thermal neutrons at the research reactor of type TRIGA II at the Institute for Nuclear Chemistry of the University Mainz. The (n,γ) reaction is utilized for the activation of stable isotopes. The irradiations are performed at a reactor power of 100 kW. The samples are measured by the gamma ray spectroscopy using a semiconductor detector. The analyses show a number of elements and admit a qualitative decision. For a quantitative analysis the measured activities are determined in relation to standard samples of the relevant nuclides.

1 Introduction

Different samples of mammoth and elephant ivory are analysed using the instrumental neutron activation analysis (INAA), a method which allows the determination of the elements without the need of chemical treatments of the sample. In a qualitative analysis the main and trace elements are measured to receive the element composition of the samples. In addition a quantitative analysis is tried using different element standards. The aim is to investigate if a distinction between mammoth and elephant ivory is possible applying the INAA. In a first series of measurements seven samples of each kind of ivory are analysed.

2 Principles of neutron activation analysis

The NAA is a highly sensitive multi-element analytical technique useful for performing qualitative and quantitative analysis of major, minor, and trace elements in samples from almost every field of scientific or technical interest. This method is able to offer sensitivities that are superior to those attainable by other ones, being recognized as the primary method employed by the National Institute of Standards and Technology to certify the concentrations of elements in standard reference materials. The particular advantage of this technique is that it does not destroy the sample since only a small amount of the sample is necessary for the analysis. The NAA technique can be classified into two categories based on whether chemical separations are employed in the procedure. For the analysis of ivory the INAA without chemical separation was used.

For the NAA the samples are irradiated with neutrons which cause an activation of the isotopes by the (n,γ) reaction using thermal neutrons since the thermal neutron cross-section for most elements is much larger than for epithermal and fast neutrons [1]. The nuclear method relies on the measurement of γ-rays emitted by the sample. The rate at which γ-rays are emitted from an element in a sample is directly proportional to the concentration of that element.

For the determination of the concentration of each element in the sample, it is required to compare the γ-ray emitted from the sample with that one of a standard, a sample with a known concentration of a certain element. The standard has to be measured following the same steps than the sample regarding irradiation, cooling and measurement time.

Once the unknown sample and the standard have been irradiated, the γ-radiation of both the sample and the standard is counted. With the measurements of the samples, it is given the activity *A* (Bq) of each element. If the concentration (ppm) and the mass (g) are known for the standard, and also the mass of the sample is known, the concentration of the element in the unknown sample can be calculated. This is done by equating the ratio of the concentration of an element in the sample and the standard to the ratio of the activities of the unknown and the standard.

$$\frac{C_{unkonwn}}{C_{s\tan dard}} = \frac{A_{unkonwn}}{A_{s\tan dard}}$$

where A is the activity in Bq. A is usually divided by the mass of the sample to obtain the activity on a per-gram basis. C is the concentration in ppm of an element within a sample or standard.

3 Measurements

The irradiations are carried out at the research reactor TRIGA Mainz (TRIGA = Training Research Isotope production General Atomic) [2,3]. This reactor is installed at the Institut für Kernchemie of the Johannes Gutenberg-Universität Mainz. It can be operated in the steady state mode with a maximum power of 100 kW_{th} and in the pulse mode with a peak power of 250 MW_{th}.
The irradiations are performed in the steady state mode at 100 kW using the pneumatic sample transfer system with a thermal neutron flux $\Phi_{th} = 1{,}7 * 10^{12}\ cm^{-2}\ s^{-1}$ and the rotary specimen rack with $\Phi_{th} = 7 * 10^{11}\ cm^{-2}\ s^{-1}$ (Fig.1). The irradiation, cooling and measuring times are summarized in table 1.

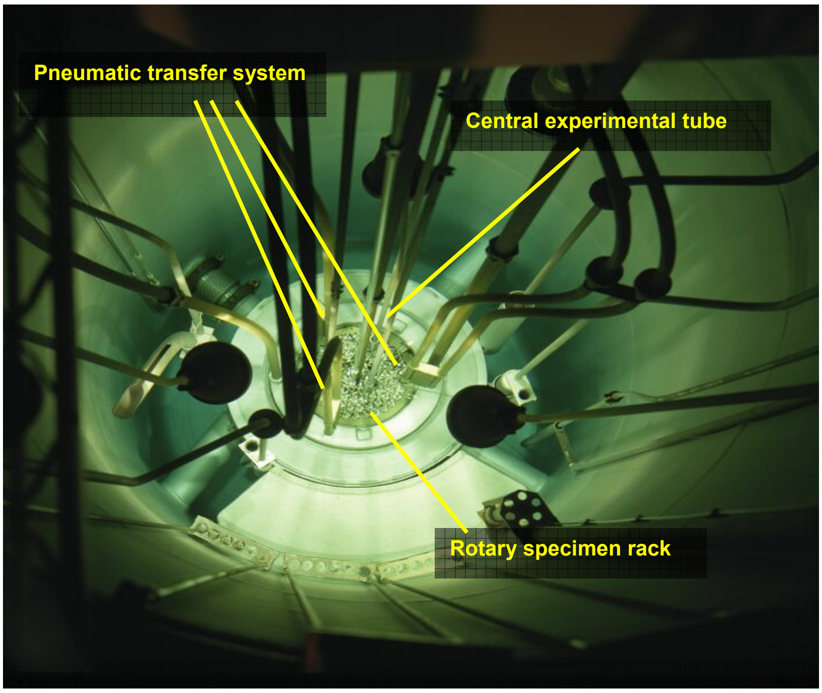

Fig. 1: Irradiation positions for the NAA at the TRIGA Mainz
Table 1: Irradiation parameters

Irradiation Position	Irradiation time	Cooling time	Measuring time
Pneumatic transfer system	10 min	ca. 10 min	10 min
Rotary specimen rack (1 h – Measurement)	6 h	ca. 15 h	1 h
Rotary specimen rack (15 h – Measurement)	6 h	ca. 8 d	15 h

Seven samples of mammoth ivory as well as elephant ivory are analysed using the measuring series in table 1. The preparation of the sample preparation occurs in a standardized procedure. The samples are cut in appropriate pieces with a mass of about 100 mg. Their surfaces are cleaned with nitric acid and de-ionized water. The γ-ray measurements were carried out using a high purity Germanium detector. For the analysis of the gamma spectra the GENIE 2000 software [4] is applied.

4 Results and discussion

The results of the ivory samples are summarized in table 2. As expected the element Ca is detected in all ivory samples as a main component as well as its homologous element Sr as a trace element. Also Na, Mg und Al are found in all samples with concentrations between 2000-18000 ppm, 200-1200 ppm, reflectively 60-290 ppm. Co, Zn, Br und Ta can be measured in most ivory samples whereas Fe can only be analysed in two elephant and three mammoth samples. The content of Zn is in the range of 10-55 ppm, Co and Sr concentrations lie between 0.1 and 1.4 ppm. Due to the lack of an element standard for Ca, Br and Ta at this time only a qualitative analysis is possible in these cases.

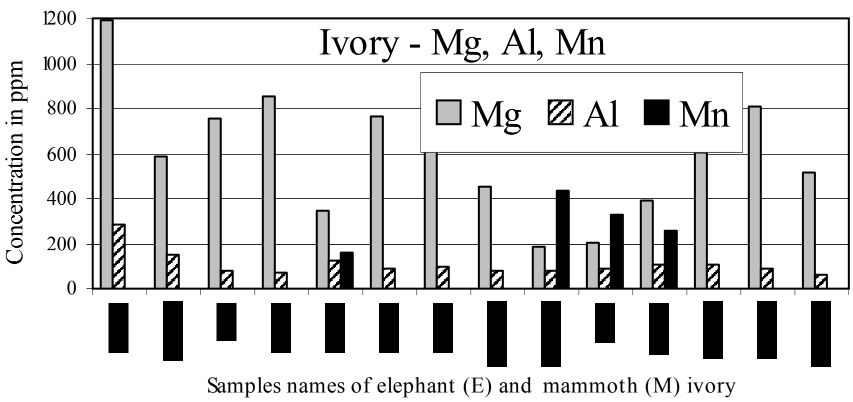

Fig. 2: Concentrations in ppm for Mg, Al and Mn in elephant (E) and mammoth (M) ivory

Table 2: The element concentrations in ppm of elephant (E) and mammoth (M) ivory are summarized. Line 2 contains the activation products which are used for the analysis. There are only qualitative values for Ca, Br and Ta.

1	Na	Mg	Al	Ca	Mn	Fe	Co	Zn	Br	Sr	Ta
2	Na-24	Mg-27	Al-28	Ca-47	Mn-56	Fe-59	Co-60	Zn-65	Br-82	Sr-87m	Ta-182
E-78	9738	1193	285	x		999	1.0	37	x	0.5	x
E-123	4789	590	150	x			0.3	10	x	0.1	x
E-4	5636	759	77	x				21		0.1	
E-20	10156	855	74	x			1.4	41		0.4	x
E-22	15622	343	122	x	159	13201	0.2	46		0.3	
E-46	11357	768	90	x				20	x	0.3	
E-47	18076	792	102	x			1.1	48	x	0.3	x
M-123	3363	453	82	x	3	509	0.8	28	x	0.1	x
M-124	7192	187	84	x	434	6555	1.3	37	x	0.2	
M-1	4362	208	92	x	327			10	x	0.2	
M-16	8452	389	111	x	255	391	0.9	55		0.3	x
M-20	6702	605	110	x			0.7	30	x	0.2	x
M-30	1909	808	89	x						0.1	
M-136	11249	519	63	x					x	0.1	

A significant difference between elephant and mammoth is observed for the element Mn, which was found in four mammoth, but only in one elephant sample (fig. 2). This is an indication for the enrichment of the sample with Mn from the soil resulting from a long deposit time.

5 Summary

The INAA is an appropriate method to determine main and trace elements in ivory. The technique is applied to some elephant and mammoth ivory samples to determine the element concentrations in both kinds of ivory. A significant difference is only observed for Mn which is found in most mammoth samples and one elephant sample. The ivory was enriched by Mn due to the long deposit time in soil.

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Tracing ivory by its chemical and isotopic composition

D.E. JACOB[1], A. STRACKE[2*], B. WIEGAND[3] AND W. DINDORF[4]
1 Department of Geosciences, Johannes Gutenberg-University, Mainz
2 Max-Planck Institut für Chemie, Dept. Geochemistry, Mainz
3 Department of Geological and Environmental Sciences, Stanford University
4 Department for Organic Chemistry, Johannes Gutenberg Universität Mainz,

*present address: Institut für Isotopengeologie/Mineral. Rohstoffe, ETH Zürich, Clausiusstr. 15, CH-8092 Zürich, Schweiz

Keywords: Ivory, trace elements, Strontium, Carbon, Nitrogen and Sulphur isotopy, Thailand
Schlagwörter: Elfenbein, Spurenelemente, Strontiumisotopie, Thailand, Kohlenstoff-isotopie, Stickstoffisotopie, Schwefelisotopie

Zusammenfassung

Die Herkunft von Elfenbein kann durch die Kombination verschiedener Methoden aus der geochemischen Routine-Analytik bestimmt werden. Am bekanntesten und erfolgreichsten dabei die Bestimmung der Isotopenzusammensetzung des Elements Strontium; jedoch können auch mit der Zusammensetzung der stabilen Isotope von Kohlenstoff, Stickstoff und Schwefel gesicherte Aussagen zur Provenienz getroffen werden. In diesem Beitrag werden die bekannten Methoden auf Elefantenelfenbein aus Thailand und Vietnam angewendet und eine für Elfenbein neue Methode der *in situ* Spurenelementbestimmung als Provenienzanzeiger evaluiert.
Das Element Strontium wird von den Elefanten mit der Nahrung aufgenommen. Die isotopische Zusammensetzung des Elements in der Nahrung, ausgedrückt als Verhältnis aus dem Isotop ^{87}Sr (aus dem natürlichen radioaktiven Zerfall von ^{87}Rb) und dem Isotop ^{86}Sr, wiederum ist von der chemischen Zusammensetzung des geologischen Untergrundes bestimmt: Junge vulkanische Gebiete wie der Bereich des Ostafrikanischen Grabens haben niedrige ^{87}Sr/^{86}Sr-Verhältnisse, während ältere Krustenteile hohe ^{87}Sr/^{86}Sr-Verhältnisse zeigen. Somit ist eine Herkunftsbestimmung oder ein Nachverfolgen migrierender Elefanten anhand ihrer Stoßzahnzusammensetzung möglich. Kohlenstoff- und Stickstoffisotope können als Anzeiger für die Nahrungszusammensetzung bzw. die Klimazone dienen. Dabei sind sehr niedrige Δ^{13}C-Werte Anzeiger für dicht bewaldete Lebensräume, während hohe Werte für Graslandschaften sprechen. In ähnlicher Weise zeigen niedrige Δ^{15}N eine feuchte Regenwald-artige Umgebung auf, während hohe Werte in Savannen zu erwarten sind. Im Vergleich mit Literaturdaten lassen sich die hier untersuchten Proben gut in entsprechende Lebensräume einordnen (Tabelle 1, Abb. 4).
Die Untersuchung der Haupt- und Spurenelementvariationen innerhalb von Stoßzahnquerschnitten zeigt allerdings keine homogene Zusammensetzung. Interessanterweise nimmt der Anteil an organischem Material (Kollagen) von außen nach innen hin zu (Abb. 1), was darauf schließen lässt, dass diese Verteilung vorteilhaft

für die Materialeigenschaften des Stoßzahns ist. Die Gehalte an Spurenelementen variieren stark über den gesamten Querschnitt des Stoßzahns (Abb. 3). Da dies auch für die Spurenelementgehalte entlang eines Stoßzahns zu vermuten ist, schränkt es die Verwendung von Spurenelementen für die genaue Herkunftsbestimmung von Elfenbein stark ein.

Table 1- Carbon, sulphur and nitrogen isotopic composition of ivory in permill relative to a standard (V-PDB for C, AIR for N and COR for S).

Sample	**$\Delta^{13}C$**	**$\Delta^{15}N$**	**$\Delta^{34}S$**
Mammoth	-18.27±0.22	+8.83±0.35	+2.86±0.20
African Eleph.	-20.36±0.11	+14.60±0.09	+4.99±0.45
Indian Eleph.	-22.63	+4.67	+6.63

1 Introduction

It is well known that the provenance of elephant ivory can be traced by its strontium isotopic composition (e.g. Koch et al., 1995; Vogel et al., 1990, van der Merwe et al., 1990). Up to know, examples in the literature mostly comprise African elephants (*Loxodonta africana*) for which the problem of ivory smuggle is most threatening. Here, we present the first results for Asian elephants from Thailand and Vietnam (*Elephas maximus*) and give an overview of the general major, trace element and isotope characteristics of ivory from different species measured *in situ* by microbeam techniques which may eventually prove to be beneficial to control ivory smuggle (e.g. Kruger, 1996, Kautenburger et al., 2004, Takeuchi et al., 1998).
Elephant ivory is the material of the incisor teeth (tusks) of elephants and consists of a carbonate-bearing calcium-phosphate mineral (dahllite). A very similar mineral (apatite) exists in the geological world. The chemical composition of dahllite, however, is determined by the animals metabolism instead of the purely physical laws that govern element partitioning in geological materials. In contrast to other teeth, the elephant incisors don't have an enamel cover except at the very tip, but consist mainly of dentine, sometimes with a thin cover of tooth cement. Dentine is less mineralized than enamel, porous and contains more organic material (around 20 wt% vs ca. 2 wt% in enamel) and is overall more bone-like than tooth enamel. These differences in material properties lead to much better potential preservation of enamel than of dentine over geological time spans with the consequence that dentine material cannot be used for palaeoclimatic reconstructions. Nevertheless, the unique material properties arising from the combination of mineral-plus-organic material make fresh ivory a sought after substance not only for ivory carving, but also in biomimetic engineering in an effort to copy the material properties of this natural high-tech material.

2 Analytical Methods

Element maps of Ca, Mg and P were measured with a Jeol JXA 8900 RL electron probe microanalyzer (EPMA) by wavelength-dispersive analysis at the Department of Geosciences, Johannes Gutenberg Universität Mainz. A beam diameter of 2µm was chosen. Trace element contents were measured by Laser Ablation ICP-MS (LA-ICP-MS) using an Agilent 7500ce quadrupole ICP-MS coupled to a New Wave Research UP123 laser ablation system. Measurements were carried out with laser energy densities of 6 J/cm^2 and helium as carrier gas. Spot sizes were 100µm and ^{43}Ca was used as the internal standard with calcium concentrations measured by EPMA. NIST SRM 612 glass was used as the external standard and data reduction was carried out with the commercial software GLITTER 4.0. Strontium isotopic compositions were determined by an Finnigan MAT 262 Thermal Ionization Mass Spectrometer at the Dept. of Geological and Environmental Sciences, Stanford University, USA after routine pre-concentration procedures carried out at the Max-Planck Institut für Chemie, Mainz. C, H and N concentrations and isotopic compositions were measured by IRMS with a Vario EL III elemental analyzer (Elementar Analysensysteme GmbH) after separation of the combustion gases by purge&trap system and reduction of H_2O to H_2 with Mg at 600°C.

2.1 Samples

All samples come from the collection of the Department of Geosciences (International Center for Ivory Studies, Mainz). The tusk pieces of African elephant, mammoth and forest elephant are of unknown provenance. The Asian samples were collected at elephant parks in Thailand and Vietnam during routine shortening of the tusks of living tame elephants.

3 Results and Discussion

The element distribution maps for a complete section through a forest elephants tusk (*Loxodonta africana cyclotis*) shows that the major constituent elements in dahllite are distributed heterogeneously (Fig.1): Calcium (Fig. 1a) and phosphorus (Fig. 1b) concentrations are highest in the outer parts of the tooth and lowest in the inner part. Magnesium (Fig. 1c) is lower (0.8 wt% MgO) in the outer ca. 2mm of the tooth where the dentine is covered by tooth cement, but has otherwise a rather constant concentration of around 3.7 wt% MgO. The simultaneously decreasing concentrations of calcium and phosphorus towards the inner part of the tooth suggest that the mineralized material is continuously replaced by organic material (collagen) towards the tooth's centre. The reason for this is unknown, but it appears possible that the distribution of soft organic material on the inside of the tooth and hard mineralized material at the outside is favourable for the material properties of the tusk. Similar trends of decreasing concentrations of calcium and phosphorus towards the centre of the tusk are also observed in sections of mammoth, African and Asian elephants. Since their tusks are of much larger diameter, however, the trends in any given part of a cross section are less pronounced than in the complete section through the thin tusk of the forest elephant.

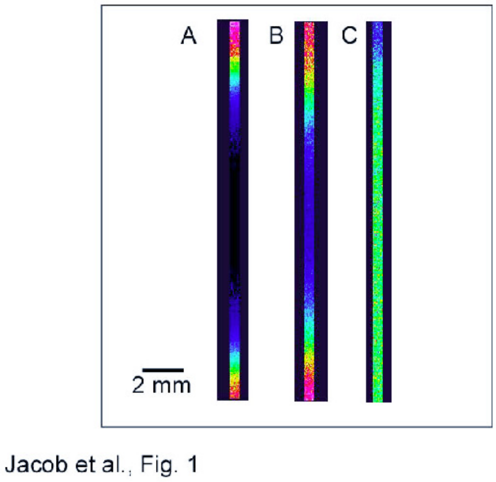

Fig. 1**:**
Element distribution maps for Calcium (Fig. 1a), phosphorus (Fig. 1b) and magnesium (Fig. 1c) in a complete transversal section through a tusk of *Loxodonta africana cyclotis*

Average trace element concentrations, measured *in situ* by LA-ICP-MS are similar between elephant species and mammoth (Fig. 2). Only zinc, strontium and barium exceed the 1 ppm (parts per million or microgram per gram) level whereas the heavy rare earth elements (gadolinium to lutetium) are below the limits of detection of this method of ca. 1ppb (parts per billion or pictogram per gram).
Similar to the major elements, the distribution of trace elements in the tusk is heterogeneous as shown by the elements strontium, barium and tin in Fig. 3.

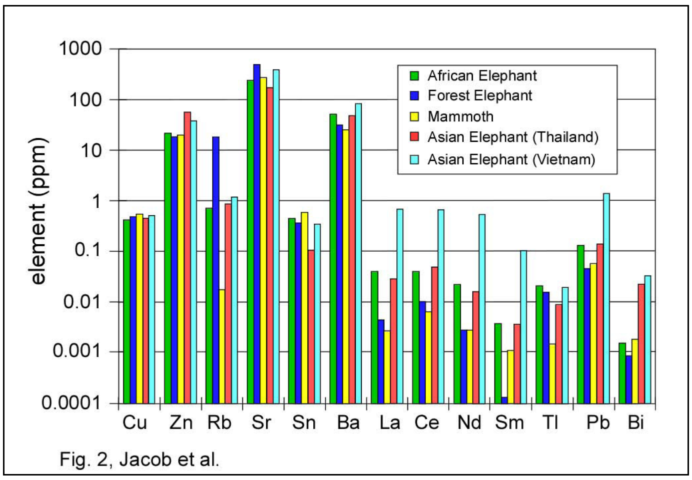

Fig.2:
Trace element concentrations in tusks from different elephant subspecies

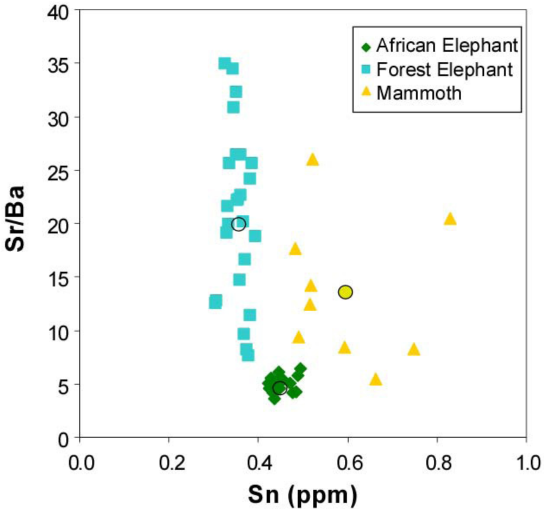

Fig. 3, Jacob et al.

Fig. 3:
Heterogeneous trace element concentrations in elephant tusks. Coloured symbols represent single spot measurements; open circle is the average value

This heterogeneity is best demonstrated at the forest elephant's tusk, because this sample represents a section covering the complete tusk, whereas the others are samples of much thicker tusks and cover a smaller section from thicker tusks. The forest elephant's tusk shows a wide range of Sr/Ba ratios from 8 to 35 at nearly constant Sn-concentrations (0.35 to 0.42 ppm). The mammoth section as well as the Asian tusk samples show more scatter in the data, while the African sample has a very constant distribution throughout the section. Strontium isotope ratios are expressed as the ratio of the radiogenic isotope ^{87}Sr which is generated by natural radioactive decay of ^{87}Rb, divided by the stable isotope ^{86}Sr (Fig. 4).

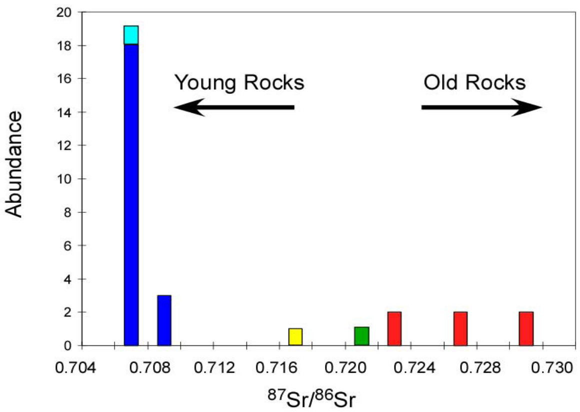

Fig. 4, Jacob et al.

Fig.4:
Strontium isotopic compositions of tusks from different elephant subspecies (colour coding as in Fig. 2), compared to literature data for Kenyan ivories (KOCH et al., 1995).

The possibility to deduce the provenance of the tusks relies on the fact that strontium is incorporated by the animal via food, whose isotopic composition reflects solely that of the geological substrate on which the plants grew. Geological areas of different ages differ significantly in their 87Sr/86Sr ratio, depending on the concentration of Rb and how much of it has decayed to ^{87}Sr over time. Figure 4 shows that the sample of the forest elephant agrees very well with samples of Kenyan elephants from the literature (Koch et al., 1995), reflecting similar geological substrate of their habitats. The samples from Thailand plot to high $^{87}Sr/^{86}Sr$ ratios indicating habitats with old geological substrate, despite their current habitat in an elephant park close to Bangkok, where only young geological substrate exists. However, these elephants were raised in the mountainous north of the country on old geological substrates and only moved into the Bangkok area much later in their lives. This shows both the potential and the caveats of the method: Sr isotopic studies enable tracing of the provenance as well as the migration of elephants, however, if the youngest part of the tooth is not sampled, the results may be misleading. To identify migration, at least older and younger parts of the tusk need to be investigated. As elephant tusks grow continuously throughout the elephants lifetime, Sr isotopes will reflect changes in substrate of a migrating elephant.

In addition to the mineralized part of the dentine, chemical information of the organic part can also be used for "fingerprinting" ivory. For this, the isotopic compositions of the elements carbon, sulphur and nitrogen can be measured directly with an Element analyzer. Carbon and nitrogen isotope ratios correspond to diet and rainfall, respectively. $\Delta^{13}C$ values less than ca. -21.5‰ are usually related to dense forest habitats, whereas higher $\Delta^{13}C$ values indicate a diet of greater grass consumption. Accordingly, low $\Delta^{15}N$ values correspond with high rainfall conditions in forest habitats, while high $\Delta^{15}N$ values are characteristic for the more arid habitats of the savannahs (e.g. van der Merwe et al., 1990). Table 1 shows the results for the mammoth sample in comparison with that of the African elephant and an Asian elephant sample. The African ivory sample is similar to samples from South Africa (Addo) or Namibia (Kaokoveld), while both the Asian and the mammoth ivory have isotopic compositions indicative for their provenance from more humid climates (van der Merwe et al., 1990). The total nitrogen content of the fossil mammoth sample is less than that of the modern ivory samples and suggests that some of the organic material has decayed in this sample. Since this process may involve fractionation of the isotopes, the results for the mammoth should be interpreted with caution.

This study, in concert with numerous other studies shows that ivory can be traced precisely by use of routine instrumental analytical techniques. However, to guarantee a sustainable success in the process of ivory smuggle restriction, it is of utmost importance to build a reference database of ivory of known provenance that is freely accessibly to the scientific community around the world. Up to now, such a database is non-existent and its setup relies entirely on the political decision-makers.

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Some notes on mammoths and mammoth tusks, the function of the tusks and problems of the mammoth ivory trade

D. MOL
Natuurhistorisch Museum Rotterdam

Keywords: Proboscidean ivory, Mammuthus primigenius, elephant ivory, morphology and internal structure of tusks, ivory trade
Schlagwörter: Rüsseltiere Elfenbein, Mammuthus primigenius, Elefantenelfenbein, Morphologie und innere Struktur von Stoßzähnen, Elfenbeinhandel

Zusammenfassung

Schon wieder ist ein Mammutkadaver im arktischen Sibirien entdeckt worden, diesmal mit einem bemerkenswert gut erhaltenen Kopf. Na und? Solche Entdeckungen von mumifizierten Mammutüberresten haben die Menschen seit Jahrhunderten in ungläubiges Erstaunen versetzt. Es ist uns bisher nicht gelungen, die verwirrenden Umwelt- und Klimabedingungen, denen die Tiere ausgesetzt waren, ganz zu verstehen. Untersuchungen des eiszeitlichen Paläoklimas befassen sich selten mit Beschreibungen der pleistozänen Mammutsteppe, geschweige denn, dass sie sich der Frage widmen, warum das Mammut ausstarb. Der vorliegende Vortrag erlaubt es uns, Wissenschaftlern über die Schulter zu schauen, während sie geschickt die Geheimnisse aufdecken, die das Yukagir-Mammut über 20.000 Jahre im eiskalten Erdreich bewahrte. Solche Entdeckungen sollten weltweit "ausposaunt" werden, so dass sich unser Bemühen auf das Verstehen der rätselhaften Vergangenheit unserer Erde konzentriert und wir die Hintergründe der heutigen klimatischen Veränderungen leichter erhellen können. Das Wissen um die Ursachen mag die heute lebenden Elefanten davor bewahren, dasselbe Schicksal zu erleiden wie jene faszinierenden Wollmammute der Vergangenheit.

Abstract

The growth, shape and function of tusks of several Proboscideans are discussed, along with some modern day commercial implications for tusk ivory. Both elephants and mammoths appear to have used their tusks as foraging tools, ornamentation and weapons. However, the change in habitat from savannah to steppe caused the woolly mammoth to lose the function of tusk as foraging tool but gain a remarkable evolutionary structure as its ornamental function. Furthermore, the commercial demand for ivory and the international regulations prohibiting any handling of modern elephant ivory do create a high demand for mammoth tusks. This brings about several complications for the enforcement of the regulations and the paleontological research of fossil remains. Good communication between commercial harvesters and paleontologists may result into a win-win situation.

1 Introduction

The woolly mammoth, *Mammuthus primigenius* (BLUMENBACH, 1799), has triggered our imaginations for centuries. This fascination is evident through ancient drawings on cave walls and endures to the present day (Mol and Van Essen, 1992, Mol et al., 2004). Apparently he was a kind of furry elephant that must have lived during the ice ages and so is pictured as a lonely leviathan, toiling arduously through the snow and ice of the North Pole in a raging blizzard, pursued by a pack of howling wolves. Misconceptions like this must be countered by looking at the fossil remains of these animals.

Woolly mammoths are extinct relatives of elephants, and lived during the Pleistocene ice ages between some 300,000 and 10,000 years ago, roaming the continents of the Northern hemisphere. This charismatic animal has been studied the most extensively of all the Pleistocene megafauna. This has been possible due to the discovery of numerous bone remains in America, Europe and Asia, particularly Arctic Siberia (Vereshchagin and Tikhonov, 1999). The persistent low temperatures there allow for preservation of soft tissues like fur, skin and muscles in the permafrost.

One of the most significant woolly mammoth finds is a complete carcass, the Adams Mammoth in 1799, with many of the fragile parts still preserved (like skin tissue, hair and genitals), now on display in the Zoological Museum of Saint Petersburg, Russia. This animal marked the start of the investigation of the woolly mammoth, with interest being renewed at intervals by later discoveries like the Berezovka Mammoth in northeast Yakutia, Russia in 1901–1902, and an almost complete, mummified carcass of a baby mammoth, Dima, in Magadan, East Russia in 1977. The world press covered the event of collecting the Jarkov Mammoth in 1999, revitalizing the interest of the western world. This discovery triggered a research project called, “Who or What Killed the Mammoths”. The project team (Mol et al., 2001a and 2001b), consisting of members from several countries, hopes to contribute to the solution of the cause for the extinction of this fascinating creature.

2 Symbols

Tusks are the very symbol of an elephant. They are, in fact, simply its upper incisors; particularly elongated and curved in the case of the woolly mammoth (Figure 1). The newly born elephant already has two milk tusks, measuring between 5 and 7 cm, crowned with a thin layer of enamel (Figure 2). Non-enamelled tusks replace these milk tusks, during the first year of the animal’s life (Figure 3). Tusks continue to grow throughout the entire life span of the elephant. In old male mammoths, tusks could reach a length of up to four meters and a weight of almost eighty kilos (180 lbs). The length of a tusk is measured along the largest radius of curvature. Roughly a third of a mammoth’s tusk was hidden in the alveolar cavity of the cranium. Females generally had thinner and less-curved tusks, which were significantly shorter, because their growth pattern slowed down from their first maternity

onwards. By examining the pulp cavity of a tusk, an expert can determine the age of an individual. A cavity filled with dentin or ivory signifies that the tusk belonged to a very old individual, while a deep, conical, empty cavity signifies that the mammoth was still young.
It is not really known how the mammoth made use of this enormous mass of ivory. Traces of abrasion, sometimes present at the very tip of a tusk, may indicate that the mammoth used tusks to plough the ground for feeding purposes. Of obvious use as defence against predators, tusks were also a weighty argument in commanding respect within the herd.

Figure 2: Milk tusk of *Mammuthus primigenius* (BLUMENBACH,1799). Collection of Jan van der Steeg (Losser), number P00170. This specimen was found in a sand and gravel pit in “Holt en Haar” near Gildehaus, Germany, about three hundred meters from the Dutch German border. Picture: Jan van der Steeg.

Figure 3: *Mammuthus primigenius* (BLUMENBACH, 1799). Left tusk of a very young individual as seen from the lateral and dorsal side. Found at Bolshoy Lyakhovsky Island, New Siberian Islands. This specimen has been collected from a severely damaged skull, which has been left in the area. Collected during the Tandem Expedition (led by the late Mr. Archangelov, summer 2001) Collection Dick Mol, Hoofddorp, number 2001-5001A and 2001-5001B. This pair of tusks is in use for analysis by Dr. D. C. Fisher and A. N. Rountrey, University of Michigan, USA, to obtain knowledge about the life history of this particular individual animal. Picture: D. C. Fisher and A. N. Rountrey, University of Michigan. Scale in centimeters.

3 The growth of tusks

Research of newborn and juvenile mammoth babies found in the permafrost of Arctic Siberia has revealed that the mature tusks are already present in the alveoles (pulp cavities). These probably would not be visible in the first few years. The mature tusks are rather straight in the first three to four years in the juvenile mammoth (Figure 3). Between five and ten years of age a slight curvature gradually develops. While maturing, this cavity steadily fills with dentine. This process also aids us in estimating the age of the animal, by observing the depth and diameter of the pulp cavity, although occasionally there is some variation. Very old animals have often little pulp cavity left as it is nearly filled with dentine. In general it can be assumed that one third to one quarter of the tusk is fixated within the alveole.

In Siberia, where huge numbers of tusks and other fossil remains have been collected and preserved in the Mammuthus museum of CERPOLEX in Khatanga (Figure 4), we have observed alveoles of only a mere 5 cm deep. Extremely worn down molars in the lower jaws of the same animals confirmed that these had lived to a very old age.

Figure 4: A part of the CERPOLEX collections in the Mammuthus museum in an underground cave in the permafrost of the village Khatanga on the Taimyr peninsula of Arctic Siberia. The fossil remains of mammoths and other Pleistocene mammals are stored at below freezing temperatures for conservation. Here a part of the perfectly conserved tusks. Pict:Francis Latreille.

Tusks grow in the tusk-socket, the alveole. There is an ongoing, continuous process whereby a very thin layer of dentine is deposited in the pulp cavity of the tusk every single moment, making it longer and longer. From the alveole the direction of growth is downwards and outwards. The tusk then curves forward, upwards and inwards again. Thus, a large, long spiralling tusk developed as the mammoth grew older (Figure 5), and the size and curvature of a tusk is another indication of whether the tusk belonged to a juvenile, an adult or an old to very old animal.

Figure 5
Dr. Christian de Marliave, secretary of the CERPOLEX research program, “Who or What Killed the Mammoths” with one of the most eye-catching tusks from the collection of CERPOLEX, Khatanga, Taimyr peninsula. Picture: Francis Latreille.

The left and right tusks are readily distinguishable due to asymmetry, as a slice of a tusk is never a perfect circle. The inner side, especially where it is secured to the alveole is usually flattened out a bit. When the tip is placed forwards as it would be in anatomical position and the flattened side is to the left then we are dealing with a right hand tusk and vice versa.

The continuous growth of the tusk leaves evidence of the particular growing conditions. Detailed composition and growth rate may reveal details about those conditions. A correct analysis of the tusk can reveal a wealth of details about the animal, like the exact age of the animal, or the physical condition during its life, or its gender, and whether and how many times a cow had given birth, etc. The last layers of dentine in the pulp cavity, where the tusk was growing, can reveal even more details about what condition and in what season the animal had died. This requires destructive research though.

4 The shape and function of the tusks

Several species of Proboscideans roamed the fields and forests of the Eurasian continent during the Pleistocene era. The best known is the woolly mammoth, characterised by spiralling tusks (Figure 5). However some mammoth species had tusks that were not so curved, for instance the southern mammoth, *Mammuthus meridionalis* (NESTI, 1825), (Figure 6), and its descendant, the steppe mammoth, *Mammuthus trogontherii* (POHLIG, 1881). They both had very impressive but less-curved tusks. These species also show considerable differences between sexes, the female tusks being much more modest. For the southern mammoth, the difference was sufficient to cause early investigators to consider the skulls of the female animals with the small tusks to be of another species, *Elephas lyrodon*

WEITHOFER, 1891, which translates to elephant with lyre-shaped tusks. Much later when much more fossil material became available, it became obvious that this species was identical to *Mammuthus meridionalis.* So the *Elephas lyrodon* elephant species was abandoned.

Figure 6
Mammuthus meridionalis (NESTI, 1825), skull fragment with enormous tusks of the southern mammoth. Val d'Arno, Italy. Collection Museo Paleontologico di Montevarchi. Pict: Christian de Marliave.

Less well known but certainly in the context of this article is the straight-tusked elephant *Elephas antiquus* FALCONER & CAUTLEY, 1847, (Figure 7). This animal, which became known as the forest elephant, is sometimes placed in the genus *Palaeoloxodon*. This common elephant of the Pleistocene, not a mammoth, appeared to be more abundant during interglacial periods and appeared to have been a forest dweller. Its molars suggest that it was specialized in browsing twigs and leaves. The tusks of these elephants were indeed almost straight, albeit very slightly bent. From the alveoles, the tusks grew slightly outwards but more strongly downwards. Next they grew slightly forwards sometimes but in other cases we see them grow inwards again. This downwards growth invites speculations as to the function of those tusks. For instance, those tusks could have been used to stick into the ground and pry roots of trees in order to topple them to be able to browse the fresh leaves at the top of the tree. The tusks may have acted as levers or hinges. The modern African elephant (*Loxodonta africana* BLUMENBACH, 1799*)*, an animal of the savannah with open light forests, shows similar behaviour. Furthermore, their tusks prove to also be quite useful for tearing off bark and stripping the trees. The straight-tusked elephant may have shown similar behaviour, in which case, the shape of the tusks may have been an adaptation to the environment.

Figure 7
Model of a straight-tusked Elephant, *Elephas antiquus* FALCONER & CUTLEY, 1847. An extinct elephant with nearly straight tusks, an adaptation to its biotope of wooded area. This elephant was a browser and probably used its tusks for demolishing roots of trees. Model made by Werner Schmid, Bernhardsthal, Austria. Picture: René Bleuanus, Sqzi Concept Studio, Arkel.

What was the purpose of the large spiralling tusks of the woolly mammoth bulls (Figure 8)? It is apparent that the higher placed inward curved tips would not be suitable for trying to dig into the ground. Furthermore, the details on the fossil feet and nails of the woolly mammoths reveal that the biotope of those animals, the treeless mammoth steppe, would have had hard firm soil. Hence quite a different environment than the African- and straight-tusked elephants' savannah or forest.

Figure 8
Model of a woolly mammoth with spiralled tusks. Model: Remie Bakker, Manimalworks, Rotterdam, 2006. Picture: René Bleuanus, Sqzi Concept Studio, Arkel.

It has been suggested that these tusks may have been used as a snow shovel. The thinking is that to reach the vegetation of the snow-covered tundra, the tusks would have been employed to sweep the snow to the side. There are a multitude of problems though for the

animal to accomplish this. The rounded tusks with a relatively small diameter, on average some 15 cm, and with the dramatic curvature, would have been highly ineffective for displacing snow. Natural selection and evolution would probably have given another shape to the tusk if it needed to be a snow shovel. Another problem would have been for the juveniles and the females, whose tusks are definitely too short even to reach the ground, let alone to manipulate the snow. In considering the snow cover scenario, another problem emerges when we observe the metabolism of modern elephants for comparison to that of mammoths. If this comparison is viable, mammoths would have had to collect some 160-200 kg of fodder per day, every day, including in the winter time. This would take some 16-18 hours per day and little or no time would be left to shovel snow.
The high crowns of the molars and their complex structure reveals that the animal was a grazer, not a browser, suggesting that the animal lived on a steppe. Furthermore, extensive research of multiple geological, paleontological and palynological evidence has revealed that the biotope of the woolly mammoth was indeed a grassy steppe with little snowfall in winter time leaving the fodder available. Also, during the growing season, grass recovers quickly from grazing damage, whereas a wet, snowy tundra would take much longer to recover, which would it make it very difficult to sustain the amount of animals that roamed on the mammoth steppe.

So, if the tusks were not suitable for assisting in foraging, what other function might they have had? One possible function for the tusks could be their use as ornamentation; they may have served as a symbol of potency. Another use may have been as weapons. As is common for many species, including modern elephants, bulls must compete for cows to mate with. Tusks come in very handy in the competition for the highest social status and the right to mate. And the competition was fierce as can be seen in damage to skulls and tusks of bulls. In many cases of broken tusks in the "fossil record" we find tusks that have been worn down and polished, which suggest that the damage happened during the life of the animal, rather than in the sediments after death (Figure 9). The polishing indicates that the tusk was used by its owner for a prolonged time after the initial damage. Another indication for the tusk as an ornamental and social function, is the large dimorphism between the sexes. The tusks of the cows gradually lost their foraging assistance function with the evolution to the grassy steppe biotope. Hence, it degenerated to a more rudimentary form as it probably had no more essential function, whereas the males continued to compete and even took the evolutionary luxury to develop extraordinary ornaments.

Figure 9
Mammuthus primigenius (BLUMENBACH, 1799), woolly mammoth tusk, which probably broke up during the life of the animal, possibly an accident but more likely during a fight with another male. After the break, the broken tip of the became polished through use during the rest of the animal's life. Location: Euro gully in front of the Dutch coast. Length of the tusk, along the outside bend is 86.5 cm.
Picture: Hans Wildschut, Hoofddorp.

5 Mammoth ivory trade

The use of mammoth ivory for the construction of tools and artifacts is known from Paleolithic time. Our ancestors used it for weapons and ornaments. The quality of the ivory of woolly mammoths found in the permafrost of Siberia as well as in North America (Alaska, USA and Yukon, Canada) is of outstanding quality and easily processed in the ivory industry.

The quantity of traded woolly mammoth ivory is substantial, and the first overview of those traded amounts was archived by Tolmachoff (1929). After this inventory, the trade continued at an accelerated pace, especially during the last decade. Apart from the commercial value for the ivory industry, individual collectors and nature museums fancy the possession of complete tusks. These intense collecting activities destroy enormous amounts of paleontological data, obstructing the investigation of Pleistocene mammals and their habitats. It's our objective to commence the discussion of how to counteract this loss of paleontological data.

6 CITES

The Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), also known as the Convention of Washington, has passed a multitude of laws for the associated countries. As of the 1980's, the modern African and Indian Elephants have been declared protected species and the trade and export of these animals and parts thereof are highly restricted by stringent rules. However, the ivory of extinct species is not covered

by legislation, and products of mammoth ivory do not require a permit for trading and importing.
Ivory products are very popular worldwide, especially in the East. Both elephant and mammoth tusks are used extensively to produce all kinds of gingerbread, and obviously the easiest obtainable raw material prevails in the industry. Before protective legislation, elephant's tusks were easily obtainable and popular. But the attention shifted to mammoth tusks after the enforcement of restrictive measures on elephant tusks. The increased interest in mammoth tusks is a strong incentive to roam the places known for finding mammoth remains, harvesting tusks.

7 Commercial Implications

Customs officers are tasked with the enforcement of import - export legislation about endangered species and their products. They frequently encounter ivory products that are subject to this legislation; however, without the required permits and licenses. The problem here is recognition. Complete tusks show up predominantly of the protected *Loxodonta africana*, and these are easy to recognize. The tusks of the woolly mammoth are highly distinctive, making them also easy to identify. But the ivory products of these two types of tusks are hard to tell apart. This complicates matters substantially. The customs officers cannot afford to interfere with legal import of mammoth ivory, nor can they permit illegal elephant ivory to pass. Moreover, the general public assumes that it is not involved in illegal activities and it will tolerate no restrictions in acquiring and transporting alleged mammoth ivory.

Certain elements in the ivory industry do not hesitate to take advantage of the complication. Often mammoth ivory and elephant ivory are mixed. Also, unscrupulous traders issue spurious certificates assuring the customer that the products were manufactured from legal woolly mammoth tusks when in fact they are crafted from illegal elephant ivory.

Untrained customs officers are insufficiently equipped to detect and expose these activities. That would require the assistance of specialists on a large scale and this is not very practical. Consequently, illegal elephant ivory trade and import and export can be disguised effectively, and is not restricted in the way that the international CITES legislation had intended.

The only obvious effective countermeasure to obstruct the illegal practices of restricted elephant ivory appears to be to impose similar or the same restrictions on all ivory products. This would facilitate the customs function, and the general public would be aware that dealing with any form of ivory is illegal. The bonus effect of such legislation would be that the free trading of mammoth ivory is obstructed. It's unclear however if this would ever be feasible, and if so, if it is effective in decreasing the demand and consequently the activities of the modern mammoth hunters.

8 Modern Mammoth Hunters

In Arctic Siberia, the native population frequently encounters excellent, preserved mammoth tusks on their random hunting trips. They are well aware of the trade value of these objects and also of the recent increased demand on the market. In view of this demand, many of them rose to the occasion to specialize in tusk hunting. Large tusk expeditions are conducted in the brief Siberian summers where only three months are suitable enough for that purpose. These expeditions cover vast areas, largely unreachable for genuine international paleontological expeditions, which are restricted not only by financial parameters but also by permissions and licenses. The hunters are only interested in harvesting tusks, and they may have no consideration in general for the paleontological value of the remains they find. There are numerous examples of how these tusk-driven quests are causing considerable damage to the valuable information that these paleontological sites contain as well (Garutt 1964, Mol et al. 2001a, b). The digging destroys stratification and disables the scientific techniques that are based on that. The removal of tusks damages other fossil remains. Unearthed mummified remains may be left behind, decaying rapidly when exposed to the elements. Fossil remains may get mixed up and scattered, blurring the view to the past, and thus effectively obstructing research into the enigmatic Pleistocene.

9 Tusk Thefts

The hunger for mammoth tusks has led to even more serious excesses, the robbery of the CERPOLEX/Mammuthus collection (Figure 4). The scientific program, "Who or What Killed the Mammoths", of CERPOLEX/Mammuthus, has accumulated a large collection of fossil remains of Pleistocene mammals of the Taimyr Peninsula in North Siberia. It's located in Khatanga in an underground ice cave with permanent sub-freezing conditions, excellently suited to preserving mummified remains. In the 1998 –2003 period a large collection of remains was accumulated, studied and documented. The collection includes the Jarkov Mammoth block that is still being processed. More than 300 tusks were part of the collection, all catalogued with location, description of the specimen, weight, and dimensions of the original animal (gender, age etc, etc), and many have been carbon dated. Some tusks have been sampled by Dr. Daniel Fisher, University of Michigan at Ann Arbor, USA for a closer investigation of the specifics of the life and death of the animal. A part of this collection, 24 of the largest tusks with weights often exceeding 40 kg, with a total weight of 1020 kg was stolen in December 2003. The suspected thieves have since been arrested and court procedures have been initiated, but the damage is considerable. The tusks were cut at the region of the pulp cavity. Then they were cut into pieces and transported in fish bags via Moscow to unknown destinations in the Far East, where they were processed on the ivory market. Some of the pieces--the bases of the tusks-- were returned, a small comfort. Similar incidents have happened to museums and similar thefts are not uncommon during expeditions.

Not all is negative--some modern mammoth hunters report their findings to the scientific community, although they may or may not have consideration about preserving the integrity of the other fossil remains. For instance, one of the mammoth hunters, Fedor Sellyakhov from Tiksi, Yakutia, discovered a mammoth mummy in the permafrost under 50 cm water on Bolshoy Lyakhovsky Island, which belongs to the New Siberian Island group. It's considered impossible for the time being to recover this mummy but he managed to cut off the tail and part of the posterior (Figure 10) for scientific study, giving us a clear insight on this part of the morphology of the woolly mammoth. The tail, by the way, is remarkably short (40.7 cm) and has a broad base (20 cm). The posterior has been preserved exceptionally well, and the anal opening measures 11 cm while the longest hair of the fur measures up to 54 cm.

Figure 10
A mammoth hunter, Fedor Sellyakhov from Tiksi, Yakutia, organizes annual expeditions to hunt for mammoth tusks on Bolshoy Lyakhovsky Island. The main objective is ivory for the commercial market. In the summer of 2003 he found a carcass of a mammoth just below water level near Shalaurova Cape. It was totally frozen in the permafrost and at that time it was not possible to recover it. He decided to cut off a sample of the rear of the animal, including the tail, and take it to Tiksi, where he donated it to Dr. Gukov of the Nature Reserve. This piece of skin was about 125 cm (47") by 61 cm (24") and covered with heavy fur. The remainder of the animal is still frozen in the permafrost under sea level waiting for whatever is to happen next. The very small ears and tail of the woolly mammoth compared to those of elephants are an adaptation to a cold environment. Pict: Dick Mol

10 Cooperation

This occurrence suggests a possible road ahead, a direct co-operation between paleontologists and mammoth hunters. Therefore CERPOLEX/Mammuthus has started an educational program for mammoth hunters to increase their awareness of the importance of the paleontological heritage. We show them the collection in the ice cave of Khatanga and the processing of the fossil remains so that they can appreciate the value of all the remains and share the obtained information. With the notion of market value of the fossils, a win-win situation may be created. Something similar has occurred in the Netherlands, where the North Sea floor contains enormous amounts of Pleistocene fossil remains of a past mammoth steppe. Sole and plaice fishermen used to discard those fossils when they cluttered their fishing nets; however, now, with the knowledge of the value of these remains, they are recovered, including the coordinates of the location, and the growing collections contain very valuable information. The native mammoth hunters covering huge areas have much more of a chance to make important discoveries than the odd paleontological expeditions. With paleontological awareness, they may minimize the damage to the discovery location and they may alert the paleontological community. This has resulted in the discovery of remarkable mammoth remains all over Arctic Siberia.

11 Acknowledgements

I would like to acknowledge the continuous help and support of Mr. Bernard Buigues, Paris, France, general director of CERPOLEX/Mammuthus and all colleagues for their cooperation and involvement in the research program "Who or What Killed the Mammoths". I would also like to thank Dr. Arun Banerjee and Dr. Giovanna Bortolaso, University Mainz, Germany, for their invitation to participate in the INCENTIVS Symposium "In the Ivory Tower" which was held in April, 2006 in Mainz. They gave me the opportunity to present some of the results of our work on mammoths and mammoth fauna in Europe, Asia and North America. Last but not least, Mr. Andre Bijkerk, Zoetermeer, the Netherlands and Ms. Joanne Ballard, New Albany, Indiana, USA, for their help in editing and support in several manuscripts on mammoth and mammoth fauna in recent years.

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4 Adressen

ARUN BANERJEE
INCENTIVS – International Centre of Ivory Studies
Johannes Gutenberg-Universität Mainz
Institut für Geowissenschaften
Becherweg 21
55099 Mainz
e-mail: banerjee@uni-mainz.de

GIOVANNA BORTOLASO
INCENTIVS – International Centre of Ivory Studies
Johannes Gutenberg-Universität Mainz
Institut für Geowissenschaften
Becherweg 21
55099 Mainz
e-mail: bortogio@students.uni-mainz.de

WILLI DINDORF
INCENTIVS – International Centre of Ivory Studies
Johannes Gutenberg-Universität Mainz
Institut für Organische Chemie
Duesbergweg 10-14
55128 Mainz
e-mail: dindorf@uni-mainz.de

WOLFGANG HOFMEISTER
Johannes Gutenberg-Universität Mainz
Institut für Geowissenschaften
Becherweg 21
55099 Mainz
e-mail: hofmeist@uni-mainz.de

IRENA PETROVIĆ-PRELEVIĆ
Johannes Gutenberg-Universität Mainz
Institut für Geowissenschaften
Becherweg 21
55099 Mainz
e-mail: ppirena2000@yahoo.co.uk

ANTHONY CUTLER
Pennsylvania State University
Dept. of Art History
225 Arts Building
University Park, PA 16802
axc6@psu.edu

ANDERS GÖTHERSTRÖM
Uppsala University
Department of Evolutionary Biology,
Norbyvägen 18D
S-752 36 Uppsala
e-mail: gotherstrom@ebc.uu.se

FRIEDER ENZMANN
Johannes Gutenberg-Universität Mainz
Institut für Geowissenschaften
Becherweg 21
55099 Mainz
e-mail: enzmann@uni-mainz.de

MICHAEL KERSTEN
Johannes Gutenberg-Universität Mainz
Becherweg 21
55099 Mainz
e-mail: kersten@uni-mainz.de

JÜRGEN GOEBBELS
Bundesanstalt für Materialforschung und -prüfung (BAM)
Unter den Eichen 87
12205 Berlin
e-mail: juergen.goebbels@bam.de

DIETMAR MEINEL
Bundesanstalt für Materialforschung und -prüfung (BAM)
Unter den Eichen 87
12205 Berlin
e-mail: dietmar meinel@bam.de

JONATHAN HAMPEL
Johannes Gutenberg-Universität Mainz
Institut für Kernchemie
Fritz-Straßmann-Weg 2
D-55128 Mainz
55099 Mainz
e-mail: jonathan.hampel@t-online.de

TOBIAS HÄGER
Johannes Gutenberg-Universität Mainz
Institut für Geowissenschaften
Becherweg 21
55099 Mainz
e-mail: tobias.haeger@uni-mainz.de

GABRIELE HAMPEL
Johannes Gutenberg-Universität Mainz
Institut für Kernchemie
Fritz-Straßmann-Weg 2
D-55128 Mainz
e-mail: gabriele.hampel@uni-mainz.de

INMACULADA CONEJOS SÁNCHEZ
Johannes Gutenberg-Universität Mainz
Institut für Kernchemie
Fritz-Straßmann-Weg 2
D-55128 Mainz
e-mail: conejoss@students.uni-mainz.de

STEPHAN ZAUNER
Johannes Gutenberg-Universität Mainz
Institut für Kernchemie
Fritz-Straßmann-Weg 2
D-55128 Mainz
e-mail: stephan.zauner@uni-mainz.de

DORRIT JACOB
Johannes Gutenberg-Universität Mainz
Institut für Geowissenschaften
Becherweg 21
55099 Mainz
e-mail: jacobd@uni-mainz.de

ANDREAS STRACKE
Max-Planck Institut für Chemie
Institut für Geowissenschaften
Aktuelle Adresse:
ETH Zürich
Institut für Isotopengeologie/Mineral. Rohstoffe
Clausiusstr. 15
CH-8092 Zürich
e-mail: stracke@erdw.ethz.ch

BETTINA WIEGAND
Stanford University
Department of Geological and Environmental Sciences
367 Panama Street
Stanford, CA 94305-2115
e-mail: bwiegand@pangea.stanford.edu

DICK MOL
Natuurhistorisch Museum Rotterdam
c/o Gudumholm 41
2133 HG Hoofddorp
e-mail: dickmol@worldonline.nl, dickmol@tiscali.nl

VERA REIFENSTEIN
Umweltstiftung WWF Germany
Rebstoeckerstrasse 55
60326 Frankfurt am Main
e-mail: zzfna03@wwf.de

CLAUDIA KITSCHKE
Umweltstiftung WWF Germany
Rebstoeckerstrasse 55
60326 Frankfurt am Main
e-mail: claudiiia@hotmail.com

STEFAN ZIEGLER
Umweltstiftung WWF Germany
Rebstoeckerstrasse 55
60326 Frankfurt am Main
e-mail: stefan.ziegler@wwf.de

BRITTA HOFMANN
Hauptzollamt Frankfurt am Main – Flughafen
Artenschutzsachbearbeitung
e-mail: britta.hofmann@hzaf-fhf.bfinv.de