

Analysis and Provenience of Minoan and Mycenaean Amber, I

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ARCHAEOLOGY and the physical sciences can hardly be said to be properly married even now, but their unofficial union is of long standing, and it has been a fruitful one even without benefit of academic clergy. Yet one must admit that some of their offspring are illegitimate in more than one sense of the word. Among these are the several attempts to determine the provenience of amber artifacts by physico-chemical means.

The geographic origin of archaeological amber finds in southern Europe is of some interest to the study of trade and cultural relations in early times, and nowhere more so than in Greece, where impressive amounts of amber ornaments have been found in Mycenaean chamber tombs, shaft graves, and *tholoi*. When the first of these were found, the once unquestioned inference that amber from digs in southern Europe *ipso facto* meant importation from the distant North was no longer secure. The discovery of more or less substantial deposits of amber-like fossil resins in Bohemia, Austria, Hungary, Rumania, Italy, France, Spain, Portugal, and the Levant had raised the inevitable question whether some of the older amber artifacts found in southern Europe might not have been fashioned from such local or nearby deposits rather than from the celebrated Gold of the North. That question was first asked by Giovanni Capellini at the Seventh International Congress of Anthropology and Prehistoric Archaeology in Stockholm in 1874.¹ Capellini's argument centered on the possible use of Bolognese amber in the early north Italian cultures of Villanova and Marzobotto. It found little response among the members of the congress. Only Cazalis de Fondouce pleaded for an open-minded consideration of Capellini's hypothesis and pointed out

¹ G. Capellini, Congrès International d'Anthropologie et d'Archéologie Préhistoriques. Compte rendu de la 7^e Session, Stockholm, 1874 (Stockholm 1876) 789-792, 799-800, 803-809.

that the stone-age amber artifacts in France might likewise have been made from the fossil resins native to that country.²

Yet, while the dust quickly settled in anthropological and archaeological circles, it catalyzed a long series of chemical investigations of fossil resins by Otto Helm, an apothecary in Danzig. Those who cherish noble notions of the objectivity of science will be saddened to find that Helm did not take up his work with an open mind: he set out explicitly³ to disprove Capellini's contention, which he misunderstood or misrepresented as dealing with the origin of amber in Etruscan tombs. Helm's writings are colored throughout by a strong conviction that Baltic amber and only Baltic amber was the raw material of prehistoric and early historic artifacts in every part of the ancient world. In the next ten years, Helm published as many papers dealing with the properties of Baltic and southern amber and with the provenience of Italian amber artifacts.⁴ During this period he developed the methods he then applied to Greek amber finds.

Amber from Mycenae

In the spring of 1883 Helm visited the National Museum in Athens and saw the amber beads which Schliemann had found in the first, third, and fourth shaft graves of the Late Helladic I Grave Circle A in the citadel of Mycenae.⁵ He applied for permission to analyze them. His first sample consisted of two grams of various fragments and gave inconclusive results. He then obtained a second sample which was a single large fragment weighing 4.1 grams. Unfortunately, the exact findspots are not indicated for any of these samples. Helm's findings are reported in two letters dated November 20 and December 17, 1884.⁶ He describes the color of his pieces as "dark hyacinthine red,"

² Cazalis de Fondouce, *ibid.* 809-810.

³ O. Helm, "Notizen über die chemische und physikalische Beschaffenheit des Bernsteins," *ArchPharm* 211 (1877) 229-246.

⁴ E.g. (a) O. Helm, "Über sicilianischen und rumänischen Bernstein," *Schriften der Naturforschenden Gesellschaft zu Danzig*, N.F. 5 nos. 1-2 (1881) 293-296; (b) *idem*, "Über sicilianischen Bernstein," *ibid.* 5 no. 3 (1882) 8-9; (c) *idem*, "Über die elementare Zusammensetzung des Ostsee-Bernsteins," *ibid.* 5 no. 3 (1882) 9-11; (d) *idem*, "Über Appeninnen-Bernstein," *ibid.* 5 no. 3 (1882) 11-14.

⁵ H. Schliemann, *Mycenae* (New York 1878) 203-204, 245, 308; German ed. (Leipzig 1878) 235, 283, 353.

⁶ O. Helm in H. Schliemann, *Tiryns* (New York 1885) 369-372; O. Helm, "Über die Herkunft des in den alten Königs-Gräbern von Mykenae gefundenen Bernsteins und über den Bernsteinsäuregehalt verschiedener fossiler Harze," *Schriften der Naturforschenden Gesellschaft zu Danzig*, N.F. 6 no. 2 (1885) 234-239.

“wax-colored,” “bright ruby-red,” “bright orange-red,” and “almost as clear as water,”⁷ and considers these in keeping with Baltic origin. He cites their hardness (not given numerically), their odor on burning, and the appearance of their weathering crust as being like those of Baltic amber. His main piece of evidence is the semi-quantitative determination of succinic acid. Helm had found this acid present in authentic samples of Baltic amber in amounts ranging from 3.2 % to 8.2 %, ⁸ but absent in most, though not all, authentic samples of non-Baltic amber.⁹ His first Mycenaean sample yielded only 1.6 %. Helm explained this, as well as the unusually high ash content of 3.2 %, by the extensive weathering which had led to “loss and change” of organic constituents and to accretion of mineral matter from the surrounding soil. While this sounds plausible enough, it is in direct contradiction of his own earlier findings that the succinic acid content of Baltic amber is about twice as great in the weathering crust (8.2 %) as it is in unweathered clear-yellow amber (3.2–4.5 %).¹⁰ It was this low succinic acid assay which moved him to ask for the second, better preserved samples in which he found 6.0 % succinic acid. Finally, Helm conducted an elemental analysis of the second sample; the results closely agreed with earlier analyses of Baltic amber:

TABLE 1. HELM'S ELEMENTAL ANALYSIS, BY PER CENT

<i>Element</i>	<i>Mycenae Bead</i>	<i>Baltic Amber</i>
Carbon	78.60	78.63
Hydrogen	10.08	10.48
Oxygen (by difference)	10.98	10.47
Sulfur	0.34	0.42

On this evidence, Helm had “no hesitation declaring the amber beads found in the royal tombs of Mycenae to be Baltic amber; there are no facts known to show that any product corresponding to the above results can be found elsewhere, *i.e.* anything chemically and physically resembling amber.” Helm was quite likely right in his assignment. The number and size of the beads in the Grave Circle A

⁷ German “fast wasserklar”; since Helm refers back to this description explicitly as a color, he must mean ‘almost colorless’ rather than ‘almost transparent’.

⁸ Helm, *supra* n.3.

⁹ Helm, *supra* n.4.

¹⁰ Helm, *supra* n.3.

tombs are in themselves arguments for their Baltic origin. His tests heighten that probability to a degree where it may well seem churlish to quarrel with it. Yet there remains the disturbing fact that Helm presented his conclusions as following inexorably from his chemical tests. They do not.

Helm's main piece of evidence is here, as in other examples of his work, the semi-quantitative determination of succinic acid. It is an objective test which can answer specific questions decisively. For example, Helm had earlier analyzed four samples of amber native to the province of Emilia and seven amber artifacts from the same region which he had obtained from the Museum of Bologna.¹¹ The total absence of succinic acid in the four geological samples and the invariable presence of it in the archaeological samples (4.8–6.3 %) support the conclusion that the seven artifacts were not fashioned from local raw material, although the modern statistically-minded archaeometrist should like to see a much larger number of analyses of geological samples before admitting to the universal statement that "all native Apennine amber is devoid of succinic acid." But the evidence does not show that no north Italic artifacts were fashioned from local Bolognese amber; nor does it show that the seven analyzed artifacts were made of Baltic amber. Yet Helm was much inclined to draw both of these conclusions, and in doing so he raised expectations about the nature of the contribution which science can make to archaeology which quite exceed the possible.

Helm persistently overrated the significance of a single experiment, while caution would warn that it is at best one small piece of a very large jigsaw puzzle. There are thousands of amber artifacts in the Mediterranean countries. They cover a large area and a long period of time. A sizable and representative fraction of them must be analyzed before it is reasonably safe to settle the kind of question which Capellini has asked and which Helm answered all too hastily.

Helm's second error was to declare an artifact to be of Baltic origin if it contained sufficient succinic acid. That would be valid if it were a fact that only Baltic amber contains comparable amounts of succinic acid. Now this is not a fact, and Helm well knew it. He had himself found 5.2 % succinic acid in a sample of Rumanian amber,¹² but he nevertheless ruled out a non-Baltic origin for the Mycenae beads on

¹¹ Helm, *supra* n.4 (d).

¹² Helm, *supra* n.4 (a).

the grounds that "Rumanian amber . . . is easily distinguished by a competent judge from Baltic amber by color, hardness, and disintegrated layer."

This is fairly characteristic of all the early work on amber: objective measurements are given great weight when they appear to be useful, but they are quickly retired in favor of the subjective decision of a "competent judge," who is invariably the author himself, when they raise problems or contradictions. The fact is that the succinic acid analysis only permits assignment of an amber artifact to one of two groups: those which are known to contain the acid (including Baltic amber, some Sicilian amber, some Rumanian amber, and several varieties from Portugal, France and Galicia¹³), and those which are known to lack it. Even this dichotomy is imperfect since there is a sizable group of fossil resins which have never been tested for succinic acid.¹⁴

Similar limitations apply to the identification by elemental composition. There is a considerable literature of quantitative analyses for carbon, hydrogen, oxygen (by difference), and sometimes sulfur in fossil resins. In view of the heterogeneity of resins, and of the changes which they have suffered during millions of years of storage under diverse geological conditions, it is not surprising to find that the composition varies rather widely within each group of samples, and that agreement of such values gives a clue, but never a proof, of identity. The same must be said of color, specific gravity, melting point, refractive index, fluorescence, and every other property which has ever been used to distinguish fossil resins from one another.

Thus the close consideration of Helm's pioneering work allows us to assess the methodological problems of any physico-chemical approach to the provenience of amber artifacts. Let us assume that all naturally occurring fossil resins have been tested for five properties, e.g. succinic acid content, elemental composition, color, hardness, and odor on burning. These may not be the most promising properties to choose, but they are the ones which Helm, in fact, chose.

(a) If no species of fossil resin agrees with any other in all five properties, then five tests will identify an artifact of unknown origin decisively.

¹³ W. LaBaume, "Zur Naturkunde und Kulturgeschichte des Bernsteins," *Schriften der Naturforschenden Gesellschaft zu Danzig*, N.F. 20 no.1 (1935) 5-48.

¹⁴ M. H. Hey, *Chemical Index of Minerals* (London 1962) sec. 33.

(b) If some species have all five properties in common, then five tests will rule out some places of origin for an artifact, but no positive identification can be made.

Life is never as neat as logic. First of all, our primary assumption has not yet been met. Many varieties of fossil resins have not been characterized.¹⁵ Secondly, the properties which Helm and others have used are not points on a scale; they are ranges, and overlapping ranges at that. There is thus no more than an *a priori* probability that a given sample would have a value within a particular range if it came from the geographical area which is characterized by that range. A more useful statistical concept is the null hypothesis, *i.e.* the chance of finding a value within the range even though the sample does *not* come from the area characterized by that range. If the null hypothesis is 0.5 (meaning that there is an even chance that the property might fall within the range even though the sample did not come from the area), then agreement in five properties would give an over-all null hypothesis of $(0.5)^5 = 0.031$; hence the degree of confidence that the artifact does come from the area would be almost 97 %. This is a highly satisfactory degree of certainty, and its attainment is in principle possible. The only final limitation is that there may be deposits of fossil resins which were worked in antiquity and which were either completely exhausted or which have not been rediscovered in modern times. An artifact from such a source would be in principle unidentifiable, and it might easily be falsely assigned to a known deposit yielding resin of closely similar or even identical properties. This is too unlikely to discourage work in this field, but it should help us to maintain a modicum of modesty in advancing claims of positive identification.

Additional tests on Schliemann's amber from Mycenae and Troy were reported by Rössler in 1899.¹⁶ He had inferred from the literature, and confirmed by experiment, that amber usually contains some sulfur while African copals never do. The qualitative test for sulfur in amber is quite simple: on heating in a test tube, the sulfur escapes as gaseous hydrogen sulfide which can be identified by its highly offensive odor or, better, by the black-brown discoloration which it imparts to a piece of paper soaked in a solution of lead

¹⁵ Hey, *supra* n.14.

¹⁶ O. Rössler, "Chemische Unterscheidung von Bernstein und Kopal," *ArchPharm* 237 (1899) 239-240.

acetate. All this had, indeed, been established by Baudrimont in 1864,¹⁷ and later analyses showed that there is sulfur not only in Baltic amber, but also in Sicilian, French, Hungarian and Rumanian amber. Rössler's tests, therefore, prove only what no one had ever seen cause to doubt: that the artifacts are some kind of amber and not African copal. The tests throw no light on the geographical origin of the amber beads.

Amber from Kakovatos

The second substantial experimental study of Mycenaean amber was made by Jonas¹⁸ in 1908 on a single large (15 × 42 mm) bead from a LM Ib *tholos* near Kakovatos which had been excavated by the German Archaeological Institute.¹⁹ From Müller's list of finds,²⁰ the bead must have come from *tholos* A. Like Helm, Jonas did all his work on one sample and was forced to assume that the origin of one bead reflects that of all the others. He conducted tests on the bead and, simultaneously, on three reference samples:

(a) an average sample of Baltic amber selected from 500 grammes of "clear" material drawn from the Prussian State Amber Works at Königsberg,

(b) a single bead of Sicilian amber (simeite) from Catania, taken from the collection of the University of Königsberg, and

(c) a single small piece of Rumanian amber (rumanite), also from the university collection.

Jonas evidently expected that the physical and chemical properties of the archaeological sample would agree with those of one of the three geological samples. The fallacy of this unwarranted restriction (made again by Reutter in 1916 in his work on amber from Swiss lacustrine settlements²¹) is obvious: the archaeological sample may be

¹⁷ E. Baudrimont, "Du soufre considéré comme l'un des éléments constituant du succin," *CR HebdAcadSc Paris* 58 (1864) 678-680; *idem*, *BullSocChim France*, sér. II 1 (1864) 328-330.

¹⁸ R. Jonas, "Bernsteinperlen aus einem mykenischen Kuppelgrabe und die Identifizierung ihrer Substanz mit Succinit," *Schriften der Physikalisch-ökonomischen Gesellschaft zu Königsberg* 49 (1908) 351-368.

¹⁹ (a) W. Dörpfeld, "Tiryns, Olympia, Pylos," *AthMitt* 32 (1907) ix; (b) *idem*, "Alt-Pylos, I. Die Kuppelgräber von Kakovatos," *ibid.* 33 (1908) 295-317; (c) K. Müller, "Alt-Pylos, II. Die Funde aus den Kuppelgräbern von Kakovatos," *ibid.* 34 (1909) 269-328.

²⁰ K. Müller, *supra* n.19 (c).

²¹ L. Reutter, "Des ambres lacustres," *CR HebdAcadSc Paris* 162 (1916) 421-423; D. Viollier and L. Reutter, "Contribution à l'étude de l'ambre préhistorique," *AnzSchweiz* N.F. 18 (1916) 169-182.

assigned to one of the tested varieties with which it most nearly agrees, while it may actually belong to one of the many varieties which were not considered for comparison.

Jonas rejected Helm's method of analysis for succinic acid (pyrolysis of the resin and collection, purification, and weighing of the succinic acid deposited in the neck of the retort) on two grounds: first, because he had insufficient material and, secondly, because he felt that "it gave no guarantee that the isolated succinic acid was an actual constituent of the amber and had not been formed in the course of pyrolysis as a fragmentation product of higher-molecular acids." There can be no quarrel with the first point, but the second one is specious: whether succinic acid pre-exists in amber or is formed in the course of destructive distillation (pyrolysis) is a very real question for the chemist who probes the molecular structure of resins, but it is irrelevant to the problem of provenance. All that matters here is that some ambers do furnish succinic acid on heating while others do not.

Jonas states that the Kakovatos bead had the same odor on rubbing and heating as Baltic amber. Neither the bead nor his Baltic reference sample would melt at temperatures up to 360°C, although (as Jonas knew) Helm had reported²² the "melting points" of Baltic amber to lie between 287° and 300°C. Fossil resins generally do not melt; they decompose, and decomposition points are notoriously difficult to reproduce. Even so, a difference of nearly 80°C is curious.

Jonas next turned to a comparison of solubilities in 96 % ethanol. He made single determinations of the Kakovatos sample (18.58 % soluble), his Baltic reference sample (21.91 %), and the Sicilian sample (14.41 %). His Rumanian sample was too small for a solubility test, and he cites earlier work by Murgoci²³ which gives the solubility of rumanite in 96 % ethanol as 6 %. These tests were thus inconclusive, which comes as no surprise. The solubility of Baltic amber in ethanol has been given as 10–12 % by Heyer,²⁴ 17–25 % by Helm,²⁵ and 14.3 % by Coffignier.²⁶ The solubilities of other fossil resins vary similarly, demonstrating once more that the wide and overlapping ranges of

²² Helm, *supra* n.3.

²³ G. Murgoci, "Gisements du succin de Roumanie . . .," *Memoriile Congresului de la Jasi* (Bucharest 1903) 1–34.

²⁴ J. C. H. Heyer, *Chemische Versuche mit Bernstein* (Erfurt 1787).

²⁵ Helm, *supra* n.3.

²⁶ G. Coffignier, "Sur la solubilité du succin," *BullSocChim France sér.IV* 5 (1909) 1101–1103.

single physical properties are inadequate for the characterization of these complex and heterogeneous mixtures.

In the end, Jonas' identification of the Kakovatos bead with Baltic amber (mineralogically: succinite) rests on his experiments with quantitative cleavage (chemically: saponification) by means of sodium methoxide, CH_3ONa , and back-titrating the excess base with standard solutions of dilute sulfuric acid. His results are given somewhat unconventionally in terms of grams of sulfuric acid equivalent to the amount of sodium methoxide which are consumed by one gram of resin. They are easily converted to the commonly cited so-called saponification numbers, defined as the number of milligrams of potassium hydroxide (even though another base, such as sodium methoxide, may have been used in the actual test) which are consumed by one gram of resin.

The saponification number (S) is the sum of two other quantities: the acid number (A), defined as the number of milligrams of potassium hydroxide consumed by one gram of resin at room temperature by the neutralization of free acids in the sample, and the ester number (E), defined as the number of grams of potassium hydroxide required to cleave all ester linkages in one gram of resin, a reaction which requires heating to be completed in a reasonable length of time. Thus $S = A + E$. Of these three quantities, S and A are determined directly by experiment, E is calculated from them. The relative values of these numbers have been of use in classifying fossil resins; most recently Chauffin²⁷ has published some careful work on the acid number of French fossil resins. Jonas determined only saponification number:

TABLE 2. JONAS' ANALYSIS BY QUANTITATIVE CLEAVAGE

Sample	Sulfuric acid equivalent to the base consumed by one gram of resin	Saponi- fication Number (S)
Kakovatos bead	0.1323 g.	151.4
Baltic amber (succinite)	0.1285 g.	147.0
Sicilian amber (sime-tite)	0.0945 g.	108.1
Rumanian amber (rumanite)	0.1273 g.	145.6

Jonas concedes that these results fail to distinguish between Baltic and Rumanian amber, and that the Kakovatos bead might hence be

²⁷ J. Chauffin, *BullMenSocLinnéenne Lyon* 31 (1962) 189-191 and 32 (1963) 103-105.

identical with either. He nevertheless identifies it with Baltic amber on the grounds that both changed in the course of saponification to a "spongy, voluminous mass which shows all the properties of the alcohol-alkali salt of succinoresinol described by Aweng." Jonas does not state what these properties are. Aweng's²⁸ succinoresinol is a very vaguely characterized fraction derived from the saponification of the alcohol-insoluble portion of succinite. Jonas goes on to make an elaborate calculation of the amount of succinic acid which he claims his tests show to be present: allowing properly for the fact that his supposed succinoresinol was derived from whole amber while Aweng's was obtained only from the alcohol-insoluble portion (first called 'succinin' by Berzelius²⁹), he calculates the amount of base required to saponify the alcohol-insoluble portion of his samples. Then, assuming that his resins have been cleaved into equivalent amounts of succinoresinol and succinic acid, he calculates the amount of succinic acid which appears to be present in his sample of succinite to 6.6 %, and in the Kakovatos bead to 7.0 %.

This adventurous extrapolation is quite untenable. Jonas simply begs the question. The calculation of 7 % succinic acid in the Kakovatos bead assumes not only that succinic acid is present, but that succinoresinol is present as well; in short, that the Kakovatos bead is succinite. At no time did Jonas prove the presence of succinic acid in any of his samples. He does claim a qualitative test for "not inconsiderable amounts" of succinic acid by the formation of the iron salt with ferric chloride from the pyrolysates and hydrolysates of all his samples save simetite. No such test is recognized. Succinic acid does form an insoluble salt with ferric ions, but so do virtually all organic acids. A simple *reductio ad absurdum* will show the unreasonableness of Jonas' procedure: application of his mathematical operations to his sample of simetite will lead to the startling conclusion that it contained 4.9 % succinic acid, and hence could not have been simetite.

Jonas would reply to this argument that his sample of simetite did not, after all, produce a "spongy, voluminous mass" on saponification while both succinite and the Kakovatos bead did, and that the latter two reacted with ferric ion while the simetite did not. That is true, but it must then be said that Jonas' identification of the Kako-

²⁸ E. Aweng, *Über den Succinit* (Diss. Bern 1895) and *ArchPharm* 232 (1894) 660-688.

²⁹ J. J. Berzelius, "Einige Bemerkungen über den Bernstein," *VetenskAcadHandling* 1827, and *Poggendorffs Annalen der Physik*, 2.F 12 (1828) 419-429.

vatos bead with Baltic succinite rests solely on the appearance of the "spongy, voluminous mass," since even the dubious ferric chloride test lumps the Kakovatos bead together with both rumanite and succinite, as do the numerical results of his saponifications.

As with Helm's work on the beads from Grave Circle A at Mycenae, Jonas' tests substantially increase the *a priori* probability that the analyzed materials are of Baltic origin, but they do not, as they claim to do, furnish any conclusive, objective, "scientific" proof to that effect.

There are several other Mycenaean amber finds which have apparently not been analyzed. The most remarkable among them are the curious gold-and-amber "diadems" from Tiryns.³⁰ Lesser pieces are known from Nauplia,³¹ Menidi (Attica),³² and Ialysos on Rhodos.³³ Wace found large quantities in the chamber tombs of Mycenae.³⁴

Amber from Crete

The large amounts of amber found at some Mycenaean sites contrasts sharply with its paucity in Minoan Crete. Of particular interest are "two small bits of amber" found in a primitive *tholos* at Porti in 1906.³⁵ They were subject of a disappointingly superficial examination by Mosso,³⁶ who simply burned one of them in an open flame. On the slight evidence that it melted and burnt with a pleasant odor without leaving any ash, Mosso declared it to be Baltic amber. Evans³⁷ very properly criticized Mosso's attribution by pointing out that the test made "falls very far short of a scientific analysis, and the behavior of the burnt fragment was only such as might have repeated itself in the case of a piece of simple resin," by which he means a non-fossil

³⁰ A. Philadelphus, *ArchDelt* 2 (1917) App. p.17.

³¹ I. Kondakis, *Athenaion* 8 (1879) 521-523; D. Philios, *ibid.* 523-526.

³² A. Furtwängler and George Loeschcke, *Mykenische Vasen* (Berlin 1886) 40.

³³ *Supra* n.32, pl. B 12 and 13.

³⁴ A. J. B. Wace, *Chamber Tombs at Mycenae* [*Archaeologia* 82] (Oxford and London 1932) 86, 204-205, plates ix, xxix, xxxvi.

³⁵ S. Xanthoudides, *The Vaulted Tombs of Mesará*, transl. J. P. Droop (London 1924) 69.

³⁶ A. Mosso, *Le Origini della civiltà mediterranea* (Milan 1910) 291-292; English transl. M. C. Harrison, *The Dawn of Mediterranean Civilization* (New York n.d.) 368-369. Mosso here erroneously reports the pieces as coming from Kumasa instead of Porti, and Evans follows him *infra* n.37 (a) but not n.37 (b).

³⁷ (a) A. Evans, "The Tomb of the Double Axes and Associated Group," *Archaeologia* 65 (1914) 44; (b) A. Evans, in preface to Xanthoudides (*supra* n.35) p. xii.

resin of local origin such as the Minoans apparently used as a sort of incense. If these fragments were indeed Baltic amber, they would represent the oldest example of it in the eastern Mediterranean. Mosso³⁸ dated the *tholos* to the end of Early Minoan or the beginning of Middle Minoan; Evans³⁹ chose EM III, or about 400 years before the next well-attested occurrence of amber in Greece. Unfortunately, there can be no re-examination, since the pieces seem to have been destroyed.⁴⁰

Evans himself found an amber disk edged with gold and two perforated beads in a chamber tomb at Isópata.⁴¹ He sent part of one bead to Otto Olshausen in Berlin, who had taken up the analysis of amber artifacts and continued it after Helm's death in 1902. Olshausen declared it to be Baltic amber, but since he did not publish details of his experimental work, it is difficult to assess the evidence. Evans reports the conclusion as having been based on (a) the appearance of the weathered bead, (b) the formation of hydrogen sulfide during dry distillation (pyrolysis), and (c) the acidic reaction of the distillate. He adds that a more complete analysis could not be made because of "some defect in the coal employed." It must be said that a great many fossil resins other than Baltic amber contain sulfur⁴² which will be converted to hydrogen sulfide on heating, and that an acidic reaction of the distillate may be caused by any volatile acid, e.g. the formic acid John found in Lebanese schraufite.⁴³ However, some of Olshausen's work notes have been posthumously published by LaBaume,⁴⁴ and from them it is clear that the evidence was somewhat stronger than Evans reported: Olshausen observed "masses" of crystals in the neck of the distillation vessel. This is a strong indication for the presence of succinic acid, but since some mishap prevented him from identifying these crystals positively, he did not include them in his report. Evans made a bare reference to a single amber bead from an LMI or II find at Arvi in southeastern Crete, but its whereabouts is not known.

³⁸ Mosso, *supra* n.36.

³⁹ Evans, *supra* n.37 (a), 44.

⁴⁰ Evans, *ibid.*

⁴¹ Evans, *supra* n.37 (a), 42-43.

⁴² Hey, *supra* n.14.

⁴³ K. John, "Bernstein und Schraufit aus dem Libanon," *Verhandl. K. K. Geol. Reichsanstalt* 1876, pp.255-257.

⁴⁴ LaBaume, *supra* n.13.

Post-Mycenaean Amber

It is well known that little amber has been found in the post-Mycenaean Greek world. Isolated finds have been made at Sparta⁴⁵ and Eleusis⁴⁶; larger quantities come from archaic Ephesus.⁴⁷ Later and far afield are two bits of amber from Tumulus II at Gordion, dated to the early sixth century B.C.⁴⁸ The smaller of these was sent to Helm by way of Olshausen and the results reported to the Körtes by the same route: the weathering crust of the sample contained 3.3 % succinic acid. Again Olshausen's notes⁴⁹ give additional details from two letters written to him by Helm: the material showed a remarkably high 'melting point' of 386°C. It is characteristic that even before he had carried out the quantitative analysis, Helm declared the sample to be succinite in his first letter on the basis of its appearance and its odor on burning.

Analysis by Infrared Spectroscopy

Our review of past work on the chemical identification of Greek amber artifacts shows that only a handful of samples has been analyzed, and that they were analyzed between 1884 and 1908 by methods which leave generous room for doubt.⁵⁰ That the conclusions have been generally accepted as reliable by archaeologists is not the archaeologists' fault; quite clearly, the analysts announced their findings with the authoritative assurance which is always expected of them, but which is not nearly as often justified. Only Professor Marinatos has recently expressed some healthy scepticism⁵¹ and said

⁴⁵ R. M. Dawkins, "Laconia, I. Excavations at Sparta, 1907. The Sanctuary of Artemis Orthia," *BSA* 13 (1906/07) 73-75, 83-84 and pl.4; J. P. Droop, *ibid.* 112-113.

⁴⁶ *ArchEph* 1885, pl.9,3, cited by G. Karo, "Die Schachtgräber von Mykenai," *AthMitt* 40 (1915) 157 n.1.

⁴⁷ D. G. Hogarth, *Excavations at Ephesus* (London 1908) 213-216, plates 47 and 48.

⁴⁸ G. and A. Körte, *Gordion: Ergebnisse der Ausgrabung im Jahre 1900* [*JdI* Suppl. 5] (Berlin 1904) 128-129.

⁴⁹ In LaBaume, *supra* n.13.

⁵⁰ O. Olshausen, "Über den alten Bernsteinhandel und die Goldfunde, II," *ZfE, Verh* 1891, pp.286-319, cites evidence which leads him to conclude that "the method of analysis has uncertainties which make a comparison between the results of different analysts difficult" and that "dry distillation (pyrolysis) is not well suited for analytical procedures." According to the data given in this reference, Helm consistently found more succinic acid than other analysts; this may be a credit to his skill, it is none to the method.

⁵¹ S. Marinatos, "The Minoan and Mycenaean Civilization and its Influence on the Mediterranean and on Europe," *Atti del VI Congresso Internazionale delle Scienze Preistoriche e Protostoriche* I (Rome n.d.) 166.

that "a new and comprehensive study of the amber question is needed, with a chemical examination of as many samples as possible, and coming from all areas available."

Not the least of the shortcomings of the succinic acid assay as developed by Helm and Olshausen are the quantities of material (in the order of 1–2 grams) which are completely destroyed in the process, and the time and skill required for a single determination. They are without doubt the main reasons why the method has not been applied as widely as Marinatos rightfully demands.⁵²

We therefore set out, some years ago, to see if modern organic analysis might not offer ways of distinguishing between mineralogical varieties of amber which would require so little material, skill, and time that they could be applied to the hundreds if not thousands of amber artifacts which await identification. We have found such a method in infrared absorption spectrophotometry. Preliminary results⁵³ and technical details⁵⁴ have been published elsewhere. We will here give only a bare outline of the principles involved. A sample of about two milligrams is ground with a hundredfold excess of potassium bromide (a salt which is transparent to infrared radiation), and the mixture is pressed into a clear pellet in an evacuable die. The spectrum of the pellet is then determined in a commercial infrared spectrophotometer. We have successfully used one of the simpler and less expensive instruments on the market, the Perkin-Elmer Model 237. The instrument records the absorption of infrared light as a function of wavelength over the range from 2.5 to 16.0 microns (4000 to 600 cm^{-1}). The absorption curve is a source of much chemical information which need not be considered here⁵⁵; for purposes of identification it is simply a sort of fingerprint of the sample. For pure compounds, identity of spectra establishes identity of chemical composition. For such complex mixtures of compounds as fossil resins, essential likeness of spectra is as much as can be expected. By recording the infrared spectra of a large number of fossil resins from every known deposit, we have found that Baltic amber has a

⁵² J. M. de Navarro, "Prehistoric Routes between Northern Europe and Italy defined by the Amber Trade," *Geogrj* 66 (1925) 481–507, made the same demand for amber analyses on a large scale for the sake of general European prehistory.

⁵³ C. W. Beck, E. Wilbur and S. Meret, "Infrared Spectra and the Origin of Amber," *Nature* 201 (1964) 256–257.

⁵⁴ C. W. Beck, E. Wilbur, S. Meret, D. Kossove and K. Kermani, "The Infrared Spectra of Amber and the Identification of Baltic Amber," *Archaeometry* 8 (1965) 96–109.

⁵⁵ See Beck *et al.*, *supra* n.54.

distinctive absorption pattern in the region between 8 and 9 microns. In a well-preserved sample, the pattern shows a perfectly flat 'shoulder' between 8.0 and 8.5 microns, followed by a peak which centers upon 8.7 microns, after which absorption diminishes sharply (figure 1, Spectrum 74). In many cases, the normally horizontal shoulder has acquired a negative slope (figure 1, Spectrum 179). This

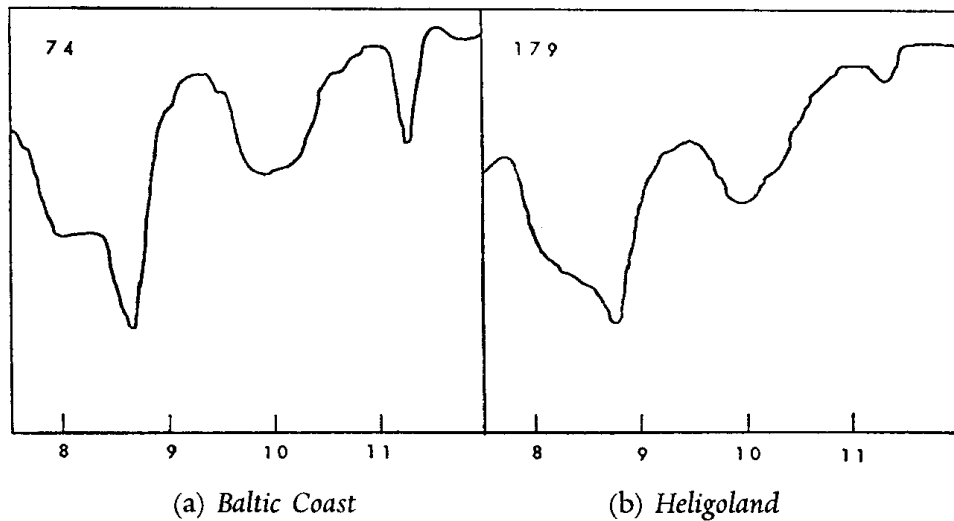


Figure 1. INFRARED SPECTRA OF BALTIC AMBER FROM 7.5 TO 12.0 MICRONS

change is invariably connected with a decrease in the intensity of an absorption peak at 11.3 microns, and we have traced both to the oxidative degradation caused by long exposure to air.⁵⁶ It is therefore not surprising that many archaeological samples show spectra (figure 2) in which these changes have occurred to varying degrees, and that the changes are more pronounced in samples which have been exposed the longest.

We think it important to state clearly the limitations of the present state of our knowledge. We hope, of course, to make further progress, but at this time it is only possible to say whether an amber artifact is Baltic or not. We have now recorded the spectra of nearly 800 amber samples of which about half are Baltic succinite and the other half are fossil resins from every part of the world. The latter show such variety in their spectra, and at the same time so much overlap among geographically separated groups, that much more evidence

⁵⁶ See Beck *et al.*, *supra* n.54.

must be gathered before a rational classification can be made. If the resins native to, say, Sicily and the Levant were formed by the same, or by closely related, species of trees, their chemical composi-

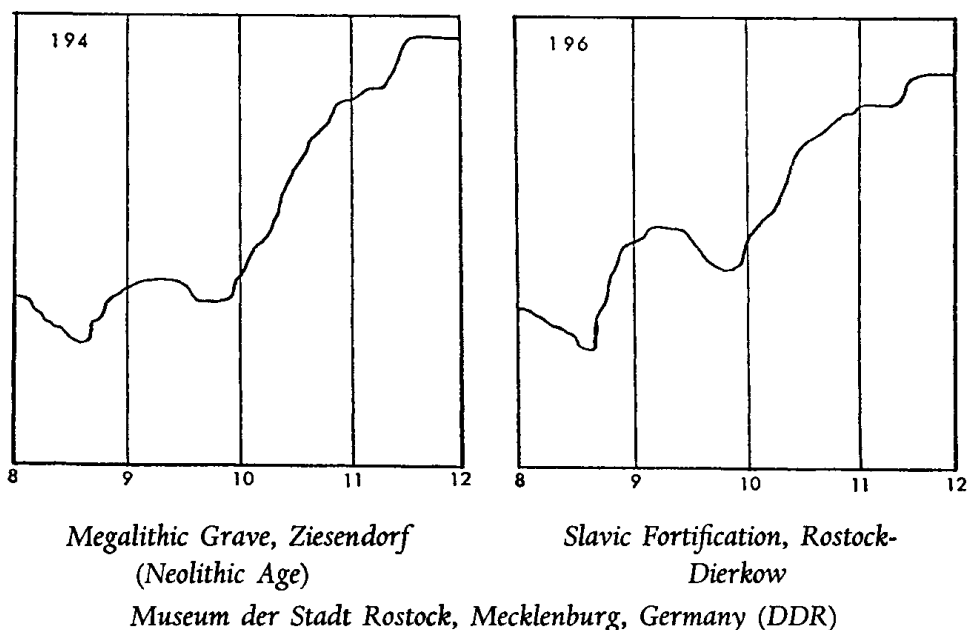


Figure 2. INFRARED SPECTRA OF ARCHAEOLOGICAL SAMPLES OF BALTIC AMBER

tion would be quite or nearly identical, and so would their spectra. Even when it is possible, classification will not necessarily solve burning archaeological questions.

However, none of the spectra of non-Baltic European amber shows features which would allow any confusion with those of Baltic amber.⁵⁷ We therefore feel very confident that an amber artifact which has the spectral features described above can be considered of Baltic origin. As mentioned before, there are Baltic samples which give such poor spectra as a result of oxidative degradation that a careful analyst should suspend judgement. Spectrum 194 in figure 2 is an example. So far, these have been few, and more often than not repeated sampling of the intractable piece has eventually brought up a spectrum which made an unequivocal decision possible. On the basis of past experience, we have no hesitation in pronouncing a

⁵⁷ The qualification 'non-Baltic European' amber is necessary because we have found spectral patterns indistinguishable from those of Baltic amber in some North American fossil resins. Though that may be electrifying news to the palaeobotanist, it is a matter of indifference to the archaeologist.

specimen to be Baltic if it gives only one characteristic Baltic spectrum among several inconclusive ones.

The ease and speed of the spectroscopic technique now permits the analysis of every known amber artifact of archaeological interest; the minuteness of the sample required allows the analysis of even small and unique finds without destroying their scientific and aesthetic value. We have begun to undertake the spectroscopic analysis of all Minoan, Mycenaean, and Greek amber artifacts, and we will report

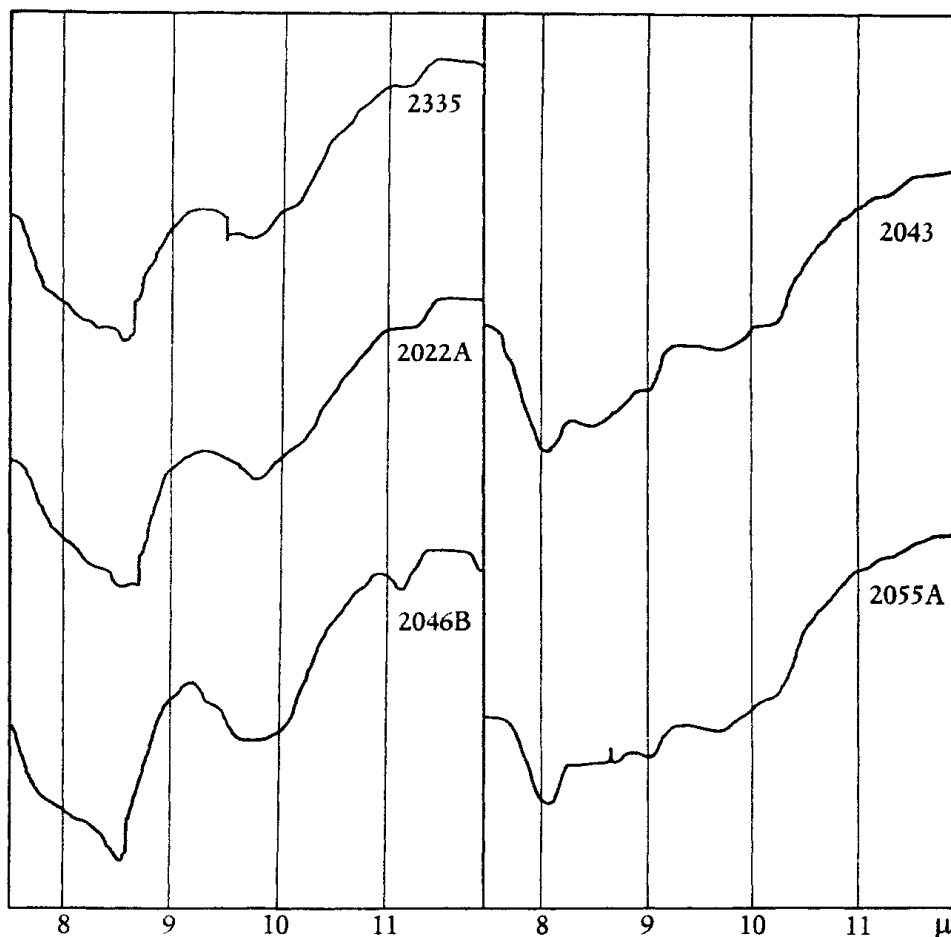


Figure 3. SPECTRA OF AMBER FRAGMENTS IN THE CHORA MUSEUM

complete results in subsequent papers in this journal. At this time the only tests made are of a handful of samples from the Museum at Chora.⁵⁸ The spectra are shown in figure 3. Sample no. 2335 comes

⁵⁸ C. W. Beck, "Determination of the Provenience of Amber by Infrared Spectrophotometry," paper read at the 67th General Meeting of the AIA, Providence, R.I., 30 December 1965.

from a shaft grave under Room 97 of the Palace of Nestor and is, of course, older than the palace. It is of Baltic origin. The other four are from the *tholos* V₁, the Vayenas *tholos*, excavated by Lord William Taylour in 1957 and described in Professor Blegen's report for that year⁵⁹ and by Taylour.⁶⁰ The latest pottery in this tomb belongs to the transition period LH II/III, but some is as old as MH. The samples numbered 2022A and 2046B are decidedly Baltic, but nos. 2043 and 2055A are just as decidedly not. The spectra of the latter two are practically identical; it is more than likely that the two samples are fragments of the same artifact. They are the first non-Baltic amber found in a Mycenaean context.

These few examples may indicate the modest questions which spectroscopic analysis can answer as well as those which remain. For the non-Baltic amber the extremely important question of origin is at this time beyond our knowledge. The spectrum leaves a number of possibilities open, among them some types of simetite from Sicily and schraufite from the Levant. Professor Marinatos has mentioned the possibility that some late Mycenaean amber may be of Sicilian origin⁶¹; we hope to settle this by further experimental work.

Amber Routes to Mycenaean Greece

Another large question concerns the precise geographical origin of Baltic amber found in the Mediterranean region and the routes along which it traveled south. The very extensive literature on the amber trade stands in need of critical review. There is a great deal of literary and archaeological evidence for Roman times, but uncertainty confounded by speculation is all that can be offered for earlier periods. For one thing, the natural distribution of Baltic amber due to diluvial and alluvial geological events is more extensive than is often realized. It extends from England across northern Germany and southern Scandinavia to deep into Russia. The Phoenicians are plausibly credited with an early sea route from England or Jutland to the eastern Mediterranean.⁶² Professor Marinatos has suggested⁶³ that such trade may have reached far back into Minoan and Mycenaean

⁵⁹ C. W. Blegen, "The Palace of Nestor Excavations of 1957," *AJA* 62 (1958) 178.

⁶⁰ W. Taylour, *The Mycenaean* (London 1964) 80-81.

⁶¹ Marinatos, *supra* n.51.

⁶² Homer, *Odyssey* 15.460.

⁶³ Marinatos, *supra* n.51.

times and that the Aeolian Islands, particularly Lipari, were important way stations on this route. We have one small piece of evidence which fit his hypothesis: a large annular fragment from Capanna F on the Aeolian island of Salina was found in association with "necklaces of hard stone beads (carnelian) and of glass paste beads of Mycenaean manufacture imported from the Aegean . . . and with pottery fragments of the periods LH IIIA2 and IIIB (1400-1250 B.C.)."⁶⁴ In the course of our nearly completed analyses of all Sicilian and Aeolian amber finds, we have established that this fragment is of Baltic origin.⁶⁵

Even so, an early eastern land route to Greece cannot be ruled out. The route need not have been very long, since Baltic amber has been carried to the very shores of the Black Sea at the end of the last Ice Age. It is worthwhile to bring the compilation of amber finds in Russia by Köppen⁶⁶ to the attention of archaeologists (figure 4). The map would surely have delighted Miss Bacon.⁶⁷ It is true that the isolated finds at the mouths of the Dnieper can hardly have been the source of the many large beads found at Mycenae and Kakovatos. Even the deposits at Kiev, which were substantial enough to encourage commercial exploitation,⁶⁸ cannot have figured prominently. Furthermore, all amber myths indicate that the material known in very early times was washed up on the shore (*succinum haustile*), not dug from the ground (*succinum fossile*). On balance, Professor Marinatos' sea route *via* Lipari to Sandy Pylos and thence to Mycenae and other inland and island sites is by far the most convincing. Hachmann has established a firm connection between Mycenaean amber ornaments and those of the Wessex-Culture,⁶⁹ but that need not mean that the amber used in their manufacture was found in England. Indeed, the quantities of amber naturally occurring in England⁷⁰ are almost certainly insufficient for the large drilled plates Hachmann discusses. England thus would seem to have been another way station, and the

⁶⁴ L. Bernabò Brea and M. Cavalier, *Il Castello di Lipari e il Museo Archeologico Eoliano* (Palermo n.d.) 21.

⁶⁵ Beck, *supra* n.58.

⁶⁶ F. T. Köppen, "Vorkommen des Bernsteins in Russland," *Petermanns geographische Mitteilungen* 39 (1893) 249-253.

⁶⁷ Janet R. Bacon, *The Voyage of the Argonauts* (London 1925).

⁶⁸ V. Chvojka, quoted by Evans, *supra* n.37 (a), 44 n.3.

⁶⁹ R. Hachmann, "Bronzezeitliche Bernsteinschieber," *BayAkadWiss Heft* 22 (1957) 1-36.

⁷⁰ H. B. Woodward, *Geology of England and Wales* (London 1887) 450-451 and earlier literature cited there.

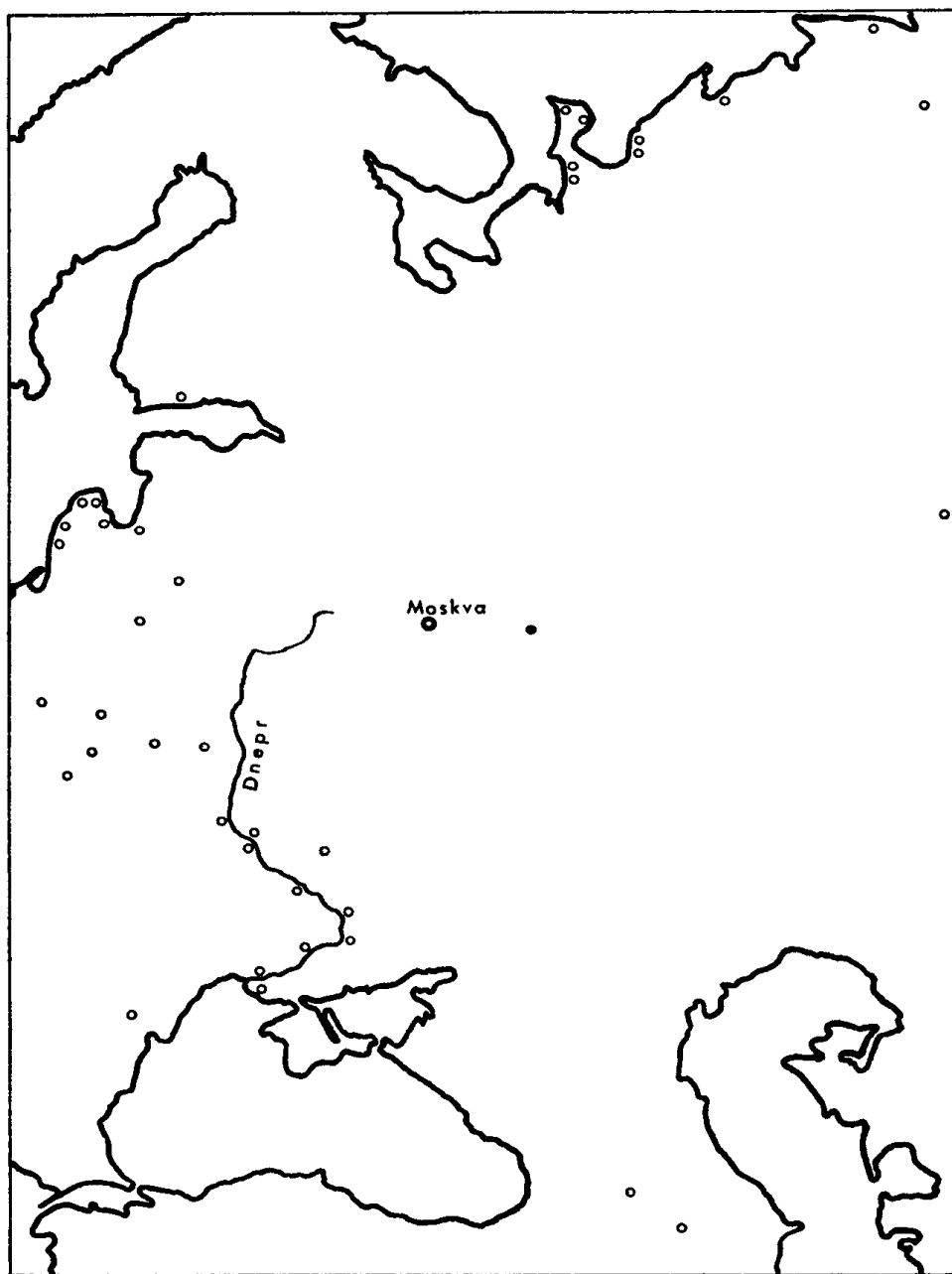


Figure 4. AMBER IN RUSSIA, AFTER KÖPPEN

origin of the raw amber, though not of the workmanship, must be sought at least in Jutland and perhaps even in the eastern Baltic.

The existence of Baltic amber in southern Russia is nevertheless significant in that it forbids us to equate the establishment of the sea route with the earliest occurrence of Baltic amber in the eastern

Mediterranean. The oldest and characteristically small finds may well have come from the immediate north of the Euxine where, even without directed search, a chance find of Baltic amber in a river bed must always have been possible. Only with the beginning of veritable hoards of large beads need we look for direct importation from the north of Europe.

There is hope that the systematic and exhaustive study of Minoan, Mycenaean, and later Greek amber artifacts by infrared spectrophotometry will help towards the solution of such problems.⁷¹

VASSAR COLLEGE

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⁷¹ We are happy to acknowledge the support of this work by the National Science Foundation through Grant GS-739 (Anthropology) for the analysis of amber artifacts and through Grant GP-4729 (Earth Sciences) for the classification of naturally occurring fossil resins.