5 & 11

January 4, 1963.

Phone 617 - 491 - 1916

Professor C. S. Smith,
31 Madison Street,
Cambridge 38, Mass.

Dear Professor Smith:

The rough draft of our grant proposal is enclosed. I hope that you will free to revise all or part of it, and to add your ideas.to the metallurgical section. The report of last year's ASCA projects is included in case you want more information about our current program.

Due to the shortness of time (which is my fault for not having written this sooner), may I trouble you to sign the three copies of the title page? Will you please send me also a copy of your biography and list of publications.

If all goes well, we plan to submit the final form of this proposal to the NSF by January 15.

With best regards,

EKR:LF

Elizabeth K. Ralph

Alloy of Au w. 2% Cu
heat in CuO

Friday

Meteorites - one sentence
Mail Friday

MASSACHUSETTS INSTITUTE OF TECHNOLOGY CAMBRIDGE 39, MASSACHUSETTS

Room 14N-321

11 January 1963

Miss Elizabeth K. Ralph
Department of Physics
University of Pennsylvania
Philadelphia 4, Pennsylvania

Dear Miss Ralph:

I'm enclosing the proposal with some changes suggested in it. Do not accept these changes if you do not like them.

The budget certainly seems to be adequate! I hardly think that I could make forty trips to Philadelphia in the course of a year and I believe the amount could be halved. It will be desirable, in fact essential, to get a microhardness device as a supplement to the metallograph, but I believe this is adequately covered in the present budget. (Incidentally, please do not buy any of this equipment without consulting me. I do not like the B & L equipment: I want to be sure that you get something more flexible and useful for low-power work as well.)

Although it is my intention to make no charge for the time that I spend on this during the academic year since it falls clearly within my duties at MIT, if an extended amount of time is called for during the summer it may be that I will request summer compensation. Unless we are very lucky in getting all of the subsidiary personnel that we want I expect that the present budget will adequately cover this.

It is obvious that nothing worthwhile will happen unless and until there is a metallurgist, or at least a metallographer, at work in the lab on selected samples. I'm assuming that Professor Maddin has in mind candidates for both of these roles. Perhaps the most important at this stage is a good metallographic technician.

I think this covers all points. Call me, either at home or at MIT depending on the time of day, if you have any questions.

Yours sincerely,

Cyril Stanley Smith
Institute Professor

CSS:mk
Enclosures

January 15, 1963

Mr. Haydn F. Morgan, Director
Project Research and Grants
3400 Walnut Street

Dear Mr. Morgan:

Twenty-three copies of our grant proposal entitled "Research in the History and Chronology of Metal~~lurgy~~" are enclosed. We should like to submit this to the Social Sciences Division of the National Science Foundation.

Since today may be the deadline for this quarter, we shall appreciate it if the proposal can be forwarded as quickly as possible. Dr. Rainey has talked by telephone to Dr. Spaulding in regard to its imminent arrival.

Sincerely yours,

Elizabeth K. Ralph

Elizabeth K. Ralph

UNIVERSITY of PENNSYLVANIA
PHILADELPHIA 4

OFFICE OF PROJECT RESEARCH AND GRANTS

Arch Techniques

January 16, 1963

National Science Foundation
Washington 25, D. C.

Attention: Dr. Spaulding
Social Sciences Division

Gentlemen:

Submitted herewith are 20 copies of a proposal for a grant to support a project entitled "Research in the History and Chronology of Metals" to be conducted under the direction of Dr. Froelich Rainey, Director, University Museum, University of Pennsylvania, and others.

The proposal has been approved by appropriate University officials and signed on behalf of the University by Dr. Gaylord P. Harnwell, President.

"I certify that the distribution of costs between the direct and indirect categories as shown in the proposal conforms to the usual accounting practices of this institution and to the distribution used by the cognizant Federal audit agency".

If any further information is needed, please let us know.

Yours very truly,

James L. Malone
Contracts Administrator

JLM:htl
encl.
cc: Dr. Rainey
Mrs. Ralph

University of Pennsylvania
Philadelphia 4, Pennsylvania

Submitted to: National Science Foundation

Title of Proposal: Research in the History and Chronology of Metals

Principal Investigators: Froelich Rainey, Director, University Museum

Cyril Smith, Institute Professor of the History of Metallurgy at M.I.T.

Robert Maddin, Director, Department of Metallurgy

Elizabeth Ralph, Associate Director, Applied Science Center for Archaeology.

Starting Date: 15 April 1963

Duration: 2 years

Total Funds Requested: ~~$138,221~~ $143,981

Date Submitted: 15 January 1963

Corporate Name of the University: The Trustees of the University of Pennsylvania, (a Pennsylvania non-profit corporation)

Contracting Office: The Office of Project Research and Grants, 3400 Walnut Street, Philadelphia 4, Pa.

Approvals:

David R. Goddard, Provost; Gaylord P. Harnwell, President
University of Pennsylvania

Froelich Rainey, Principal Investigator
Director, University Museum, University of Pennsylvania

Cyril Smith, Principal Investigator
Professor of the History of Metallurgy at M.I.T.

Robert Maddin, Principal Investigator
Director, Department of Metallurgy

Elizabeth Ralph, Principal Investigator
Associate Director, Applied Science Center
for Archaeology

RESEARCH IN THE HISTORY AND CHRONOLOGY OF METALS

I. ABSTRACT

Funds for the following projects are requested:

A. Metallurgical studies pertaining to archaeology and the history of metals, and the interrelationship between our society and the use of metals.

B. Studies of Sumerian technology.

C. Egypt.

1. Pilot dendrochronological project to determine the feasibility of creating a master tree-ring log for ancient Egypt and its possible extension in the Near East.

2. Collection of ancient metals.

D. Staff additions for increased competence.

1. Physicist

2. Student Assistants

II. Description of Research

The studies proposed of the origins of fabricated metals, metal technology, and research in ways of determining their ages are envisaged as appropriate new projects to be undertaken in the University Museum because of the existence of the Applied Science Center for Archaeology (ASCA), which was initiated in 1960 by Froelich Rainey, Director. The start and subsequent growth of ASCA were made possible by grants (G-13256, G-18571, and GS-16) from the National Science Foundation. The main projects of this center have been (1) the development and use of instruments for underground exploration; (2) the application of various chemical and physical techniques for analyses, including experiments with the thermoluminescence technique of dating pottery; identifications, and dating, and (3) the establishment of an information and reference center. This program is described in detail in the original grant proposals and in the present one (NSF GS-16). Projects completed during the past "grant" year are described in the report of NSF grant G-18571.

Carbon-14 dating, one of the greatest contributions of the physical sciences to archaeological research, has been in process at the University of Pennsylvania since 1951. The radiocarbon laboratory was initiated also by Froelich Rainey, and has been directed by Elizabeth Ralph. It is supported by the University of Pennsylvania and its main function is the dating of archaeological samples which pertain to the studies of members of the staff of the University Museum. In addition, basic methodological studies, supported by NSF grant GP-405, are being conducted.

This proposal embodies requests for several research projects which, at first glance, may seem diverse, especially in regard to the variety of scientific disciplines involved. However, all contribute directly to the general progress in the application of advances in scientific techniques to archaeology, anthro-

pology, to the history of metallurgy, ehcmistry, and other physical sciences, and to the interrelationship between our society and the use of metals.

The main emphasis in this proposal is on the expansion of ASCA to include a metallurgical branch. It is envisaged that this will be one of the most significant contributions of our program because of the active collaboration of Professor Cyril Stanley Smith, Institute Professor of Metallurgy, and Professor of History of Science and Technology at Massachusetts Institute of Technology. (Professor Smith is well known for his previous studies of the history of metallurgy, and for the application of metallographic methods to the study of archaeological materials.)

A. Metallurgical Studies

Because of the ASCA program which has now been growing for two years and of the great collections of the University Museum and of the availability of members of the staff of the University Museum for consultation, Prof. Smith has offered his services for assistance in the establishment of this department, for consultation and the training of a young metallurgist. This contact was an outgrowth of a conversation with Robert Maddin, Director of the Department of Metallurgy at the University of Pennsylvania. Prof. Maddin has also promised his assistance with this program. The benefits of Prof. Smith's and Maddin's services will be numerous. Problems occur daily in the course of chemical analyses of metals now being performed by M. Han and E. Parkinson of the ASCA staff and on our behalf by other institutions. Many of these require metallurgical examination and/or interpretation by an authority. For the latter Prof. Smith's great interest in ferrous metals and Prof. Maddin's knowledge of non-ferrous, and their combined knowledge of the history of metals will be invaluable. Another example, which must be supervised by metallurgical scholars, is our study of gold objects in order to find a means of differentiating between the ancient ones and the fakes -- now, a serious problem, especially, for objects from Iran. Because of the increasing

abundance of faked objects it is becoming difficult for archaeologists to study the true cultures as revealed by the artifacts fabricated by the original makers. Metallurgical studies directed toward the determination of possible surface changes with time due to diffusion or other causes are planned.

Among new projects to be initiated by Prof. Smith is the study of ancient iron objects which will not only contribute to our present knowledge of iron fabrication from the archaeological point of view but will contribute also the history of iron metallurgy. Particular attention will be paid to evidence for the origin of the intentional manufacture of steel and its intentional heat treatment. The emphasis in this part of the study will be on evidence for the changing nature of iron-and-steel-making techniques and their effectiveness, as well as their spread from points of origin. Because of the extensive work that has already been done on non-ferrous metals, iron and especially the introduction of steel, will be primarily studied. Since most early samples of iron are heavily corroded and the structure cannot yet be deduced from the mass of rust that remains, a special effort will be devoted to an attempt to identify slag inclusions from the iron as they appear in the corrosion products.

It is conceivable that new information about meteoritic iron (the source material for many early objects) will be obtained, and samples may become available for isotopic study for assaying the constancy of cosmic ray flux, and perhaps the isotope measurements may indicate if all worked pieces of meteoric iron arrived at about the time they were made, which would indicate observed falls.

A primary benefit from this program will be the training of a scientist in an entirely new interdisciplinary field. To our knowledge there are very few people who have an adequate knowledge of engineering and of the social sciences, or more specifically, of metallurgy and of archaeology (both historic and prehistoric).

As this program expands, it is anticipated that this new field of studies will attract many young scientists, especially, ones with a desire to learn more than one specific branch of the arts or sciences.

An immediate goal of our particular program will be the compilation of a master catalog of information obtained by analytic, microstructural, hardness, and other studies of ancient metals. This will form the documentary background for comparison and identification and dating of objects found in the future, and the basis for sound research in these fields.

B. Studies of Sumerian Technology

Another project proposed, which is related to the history of metallurgy, is the study of Sumerian technology, In collaboration with Samuel Kramer, Curator of Sumerian Tablet Collections, it is suggested that a young cuneiform scholar devote several years to the study of metals and metal technology in the Ancient Near East, as evidenced in the cuneiform documents, and particularly in the Sumerian literary works now being pieced together and translated primarily at the University Museum, from some 5000 tablets and fragments scattered throughout the museums the world over.

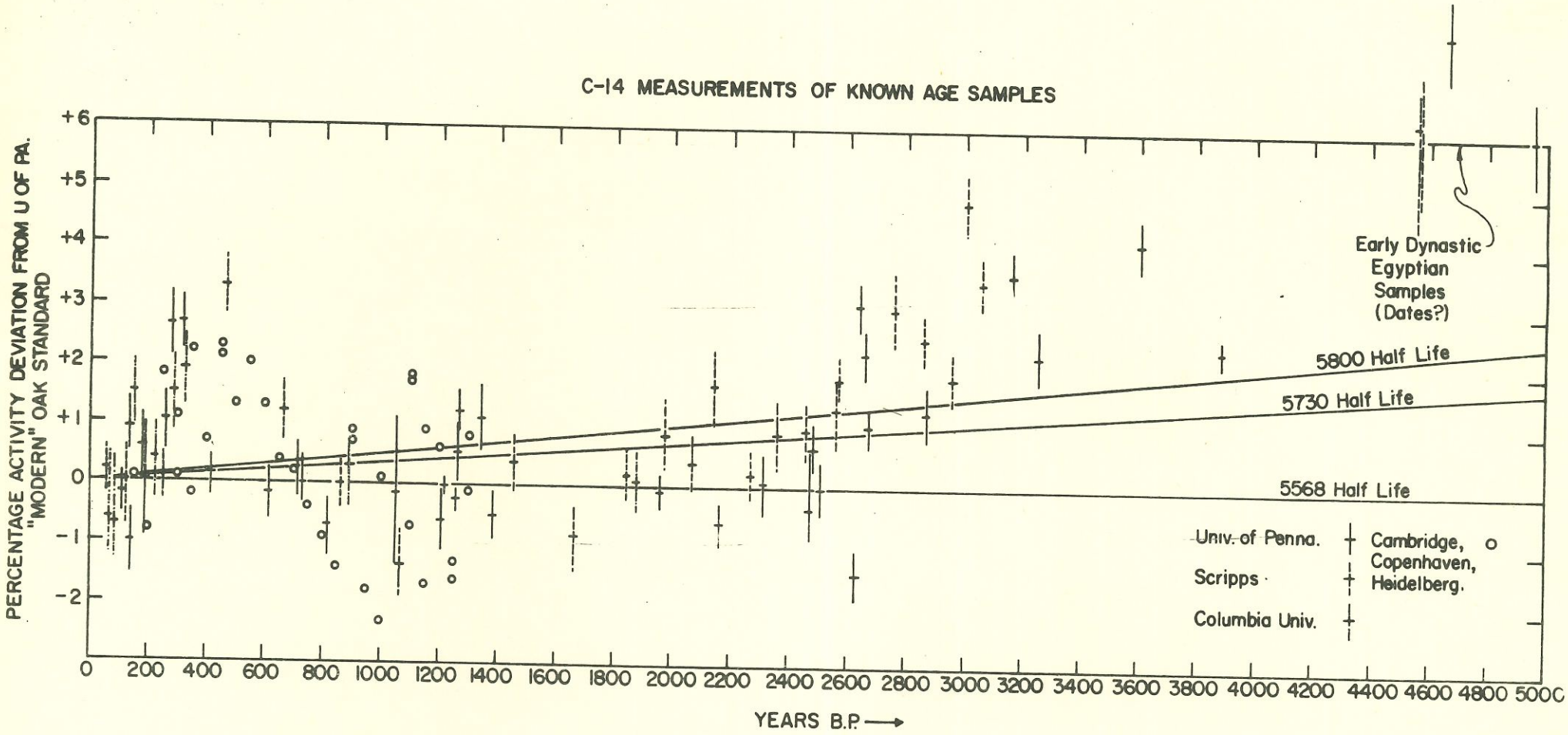
C. Egypt

1. Pilot Dendrochronological Project

The studies of the beginnings of metallurgy and of ancient technologies will not be complete without a means of dating the objects studied. Since many will be dependent upon the precise dating of the early dynastic and predynastic Egyptian and related Near Eastern cultures, we turn our attention to dendrochronology after a brief review of the limitations of carbon-14 dating.

The program of methodological studies in the radiocarbon laboratory at the University of Pennsylvania (presently financed by NSF grant GP-405) has been based on the dating of samples of known age. These afford the materials for the determination of the constancy of the atmospheric C-14 inventory, of which one of the major factors is the cosmic ray intensity. These problems are discussed more fully in the grant proposal (GP-405). The C-14 results of these measurements and those made by other laboratories

indicate that there have been changes (see Fig. 1) of the order of a few percent in the atmospheric C-14 inventory in past times. There is a definite short-term peak around A.D. 1700 to 1500, but more alarming is the upward trend in C-14 counting rates going back in time beyond 500 B.C. Is this a continuous trend and an indication of greater cosmic ray activity and/or very different equilibrium conditions (primarily between the atmosphere and the oceans, the largest reservoirs of carbon) or is it cyclic? By means of C-14 dating, the answer may be found only with samples of known age from these ancient periods. There is now hope (Ferguson, 1962) of extending the tree-ring dating of Bristlecone Pines (Schulman, 1958) beyond 2000 B.C. and if floaters now known to exist date back to 4000 B.C. or more, it may be possible to croos-date them and thus determine their true ages. However, this latter possibility is, at present, only a hope. We feel that there is a need for a second approach to this problem and that this may be provided by the creation of a master tree-ring log for ancient Egypt. The additional benefit will be the accurate dating of the early dynasties, now subject to conjecture. This would depend upon the existence of sufficient samples of wood and of the time that the early Egyptians first began importing trees which can be cross-dated from Lebanon and other "sensitive" regions. A brief survey trip made on our behalf by Dr. Bryant Bannister (Laboratory of Tree-Ring Research, University of Arizona) to Egypt and to European museums in the summer of 1961 has encouraged us to believe that sufficient wood does exist. To test its datability, a pilot project is proposed -- namely, to determine the interval between the date


C-14 MEASUREMENTS OF KNOWN AGE SAMPLES
PERCENTAGE ACTIVITY DEVIATION FROM U OF PA. "MODERN" OAK STANDARD
+6
+5
+4
+3
+2
+1
0
-1
-2
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800 4000 4200 4400 4600 4800 5000
YEARS B.P.
Early Dynastic Egyptian Samples (Dates?)
5800 Half Life
5730 Half Life
5568 Half Life
Univ. of Penna.
Scripps
Columbia Univ.
Cambridge,
Copenhaven,
Heidelberg.

of construction of the burial chamber in the pyramid of Meidum and the upper chamber in the Bent Pyramid of Dashshur. This project was suggested and will be carried out in collaboration with I. E. S. Edwards (Keeper of Egyptian Antiquities, British Museum). A similar pilot project was carried out by Dr. Bannister at Gordion, Turkey in 1961 and the results, which are presently being compiled, show that cross dating of logs from the large tomb built in 725 B.C. (Young, 1958) is possible. These samples afford a floating chronology from 725 to 1400 B.C. As new ones are excavated, it is hoped that this can be brought forward to overlap with buildings of 500 B.C. and perhaps to the present time.

The collection of samples for this project would necessarily be carried out mostly in Egypt. It will now be possible to do this because of the change in attitude of the Egyptian government as a result of the salvage program in Nubia, and will be facilitated greatly for us because of the active cooperation of Dr. Zaky Iskander, Director of the Laboratory at the Cairo Museum.

2. Collection of Ancient Metals

With the assistance of Dr. Iskander, who has offered his help with the collection of samples during the academic year 1963-1964, it will be possible also to study and to sample for analysis, many ancient Egyptian metal objects. Preliminary studies made recently by Professor Smith of an iron spear from Nubia (12th Dynasty) have demonstrated the benefits and information to be derived from careful metallurgical examination of the ancient Egyptian metals. The structure of this spear from Nubia shows that it is unmistakably smelted iron (not meteoritic) with a small grain size, no carbon, and with a rather

fine distribution of slag. It will be necessary to examine many more samples before it can be decided if the techniques were fortuitous or intentional. Because ferrous metals were less important in Egypt than elsewhere, the cooperation of the curators of the University Museum, other archaeologists, and museums will be sought to obtain samples of iron and steel from Anatolia, Mesopotamia, Iran, and elsewhere. The development of the techniques, not of the civilization, is the aim of the study.

D. Staff Additions

In the pursuance of these new projects and to help with the ones now in process in ASCA, there is a need for the services of a young physicist. It is anticipated that an Oxford graduate who has worked directly under Drs. E. T. Hall and M. J. Aitken of the Research Laboratory for Archaeology and the History of Art, Oxford University, England, will be available at the start of the academic year in 1963. Needless to say, his education in physics and his training in the laboratory at Oxford will make him qualified to contribute immediately to the progress of the ASCA projects. Among these are assistance to Profs. Smith and Maddin and their assistant in the performance of metallurgical examinations for which physical apparatus is required; with the development of the thermoluminescence technique of dating pottery; and with the experiments being conducted toward the development of better instruments for underground exploration.

It is anticipated that a research assistant will be needed for help with laboratory projects, instruments, and field surveys as well as several part-time student assistants.

III. Facilities

Facilities now available at the University of Pennsylvania and sponsored by the University Museum are the radiocarbon, chemical and the new laboratories of the Applied Science Center for Archaeology. Space for the latter two and for the expansion of the last has been provided in the University Museum. Experiments with tree-ring dating are also being carried out in conjunction with the radiocarbon program. In addition, equipment is available in the Departments of Metallurgy, Chemistry, and Physics. The facilities contributed by the University will be greatly expanded by the addition of the new Materials Center (presently under construction) in which a large well-equipped Analytical Laboratory, including all of the latest equipment for metallurgical, physical, and chemical analysis, will be located.

IV. Personnel

Biographical sketches and bibliographies of the principal investigators are included with this proposal. The persons who will be actively engaged in this program are as follows:

Dr. Froelich Rainey: Principal Investigator, Director of the University Museum and of ASCA
Miss Elizabeth K. Ralph: Associate Director of ASCA, Principal Investigator
Dr. Cyril S. Smith: Ferrous Metallurgy, Principal Investigator
Dr. Robert Maddin: Non-ferrous Metallurgy, Principal Investigator

Dr. Samuel Kramer: Cuneiform
Mr. Robert Dyson: Near Eastern Archaeology
Dr. Henry Michael: Dendrochronology
Mr. Mark C. Han: Research Chemist
Mr. Robert Stuckenrath, Jr.: Radiocarbon Laboratory

Mr. A. E. Parkinson: Chemist
Miss Jeanette Flamm: Information Center
Mr. Hamilton Carson: Instrument Surveys and Dendrochronology
Mr. Gray MacLaughlin: Electronics and Instrumentation Consultant

Collaborating archaeologists from the University of Pennsylvania are:

Dr. Alfred Kidder II: South America and Mesoamerica
Dr. Linton Satterthwaite: Mesoamerica
Dr. William R. Coe: Mesoamerica
Dr. Rodney S. Young: Anatolia
Dr. G. Roger Edwards: Anatolia

Dr. Ellen Kohler: Anatolia
Mr. George F. Bass: Underwater Archaeology
Dr. Kelly Simpson: Egyptology
Dr. Carleton S. Coon: Middle East
Dr. James B. Pritchard: Biblical Archaeology
Mr. Bernard Wailes: European Archaeology

Collaborating scholars from other institutions are:

Dr. Zaky Iskander: Director of the Laboratory of the Cairo Museum and in charge of the preservation of antiquities, Department of Antiquities, Cairo, Egypt

Dr. Bryant Bannister: Assistant Professor of Dendrochronology, Laboratory of Tree-Ring Research, The University of Arizona, Tucson, Arizona

Dr. J. E. S. Edwards: Keeper of Egyptian Antiquities, British Museum, London, England

Dr. M. J. Aitken: Associate Director of the Research Laboratory for Archaeology and the History of Art, Oxford University, England

V. Budget

First Year:

Salaries		
Summer participation of C. S. Smith	$7 000	
Metallurgist	9 000	
Physicist	3 000	
Sumerian technologist	5 000	
Research assistant (advanced graduate student)	5 000	
Student assistants, part-time	4 000	
Total salaries		$33 000
Employee Benefits (9.3% of salaries)		3 534
Equipment*		
Metallograph	4 500	
Polishing equipment, mounting press and minor machine shop tools	3 000	
Improved laboratory facilities (lighting, gas, etc.)	1 000	
Books, references, periodicals	500	
Expendable supplies, materials, and small apparatus	3 000	
Total equipment		12 000
Travel		
Egypt and return (two dendrochronologists and one metallurgist)	3 000	
Expenses of Prof. Smith in commuting from Boston	1 000	
Tucson, Arizona and return (2 trips for collaboration with Laboratory of Tree-Ring Research)	600	
Misc. travel, local trips and supervisory trips by one or more of principal investigators	1 500	
Total travel		6 100
Sub-Total		$59 634
Overhead - ~~20%~~ 25%		14 909 ~~11 927~~
TOTAL FIRST YEAR		74 543 ~~$71 561~~

*Major capital expenditures are not required because of the availability of these instruments (X-ray apparatus, electron microscope, mass spectrograph, etc.) in the Departments of Metallurgy, Physics, Chemistry, and in the new Materials Center.

B. Budget (Continued)

Second Year:

Salaries			
Summer participation of C. S. Smith	$7 000		
Metallurgist	10 000		
Physicist	9 000		
Sumerian technologist	5 500		
Research assistant	5 500		
Student assistants, part-time	4 400		
Total salaries		$41 400	
Employee benefits (9.3% of salaries)		3 850	
Equipment			
New instruments - metallurgical, physical or chemical	3 000		
Books, references, periodicals	500		
Expendable supplies, materials, and small apparatus	3 000		
Total equipment		6 500	
Travel			
Europe and return for additional sample collection, delivery of papers at conferences (2-3 trips)	2 500		
Expenses of Prof. Smith in commuting from Boston	1 000		
Tucson, Arizona and return	300		
Total travel		3 800	
Sub-total			$55 550
Overhead ~~20%~~ 25%			~~11 110~~ 13,888
TOTAL SECOND YEAR			~~$66 660~~ 69,438
TOTAL TWO YEARS			~~$133 221~~ 133,991

REFERENCES

Ferguson, Wesley
1962, Personal communication

Schulman
1958, National Geographic, "Bristlecone Pine, Oldest Known Living Thing," vol. 113, No. 3, pp. 355-72

Young, R. S.
1958, The Gordion Campaign of 1957: "Preliminary Report" American Journal of Archaeology, Vol. 62, pp. 147-54

SMITH, CYRIL STANLEY
Massachusetts Institute of Technology, Cambridge 39, Massachusetts

Born: Birmingham, England, 4 October 1903. Naturalized U. S. citizen, 1940.

Education: B.Sc., Birmingham, 1924. D.Sc., M.I.T., 1926

Research Associate, Mass. Institute of Technology, 1925-27. Research Metallurgist, American Brass Company, Waterbury, Conn., 1927-42. Research Supervisor, National Defense Research Committee, Washington, D.C. 1942-42. Associate Division Leader in Charge of Metallurgy, Los Alamos Scientific Laboratory, 1943-46. Director, Institute for the Study of Metals, University of Chicago, 1946-56. Professor of Metallurgy, University of Chicago, 1946-61. Institute Professor, Professor of History of Technology and Science, and Professor of Metallurgy, Mass. Institute of Technology, 1961-.

Awards: U.S. Medal for Merit, 1946. Clamer Medal, Franklin Institute, 1952. AIME Mathewson Award, 1936. AIME Hunt Award, 1934. A.S.M. Gold Medal, 1961. Pfizer Prize, History of Science Society. AIME Douglas Medal, 1963.

Lectureships: Campbell Memorial Lecturer, A.S.M., 1952. Institute of Metals Division Lecturer, AIME, 1948.

Member, General Advisory Committee, U.S. Atomic Energy Commission, 1946-52. Member, President's Science Advisory Committee, 1959.

Member of following scientific societies: National Academy of Sciences, American Philosophical Society, American Academy of Arts and Sciences, Academie Internationale d'Histoire des Sciences, American Physical Society (Chairman, Solid State Physics Division, 1948), American Institute of Mining and Metallurgical Engineers (Chairman, Institute of Metals Division, 1943), American Society for Metals, History of Science Society, Society for History of Technology (President, 1963-), Iron and Steel Institute (London), Institute of Metals (London), Newcomen Society.

Chief fields of research: Physical metallurgy. Role of interface energy and topology in structure of polycrystalline materials. Historical interaction between science and technology.

Hobbies: Collection of books important in metallurgical history; Oriental metalwork.

Selected Publications: The Pirotechnia of Vannaccio Biringuccio, ed. and trans. with M.T. Gnudi, New York, 1942, reprinted 1943, 1959. Structure and Properties of solid surfaces, ed. with R. Gomer, Chicago, 1953. A History of Metallography: The Development of Ideas on the Structure of Metals to 1890, Chicago, 1960. On Divers Arts: the Treatise of Theophilus, ed. and trans. with J.G. Hawthorne, Chicago, 1963. Also numerous papers in metallurgical and physical journals.

8 Nov 1962

PUBLICATIONS IN THE HISTORY OF SCIENCE AND TECHNOLOGY
By Cyril Stanley Smith

BOOKS:

Smith, Cyril S. A History of Metallography: The Development of Ideas on the Structure of Metals to 1890. Chicago: The University of Chicago Press, 1960.

Ed., Rene Reaumur, Memoirs on Steel and Iron. Trans. by A.G. Sisco. Chicago: University of Chicago Press, 1956.

Ed., Vannuccio Biringucci, Of Typecasting in the Sixteenth Century. Trans. with M.T. Gnudi. New Haven: The Columbiad Club, 1941.

Ed. and Trans. with A.G. Sisco, Bergwerck und Probierbuchlein. New York: American Institute of Mining and Metallurgical Engineers, 1949.

Ed. and Trans. with M.T. Gnudi, The Pirotechnia of Vannuccio Biringuccio. New York: American Institute of Mining and Metallurgical Engineers, 1942. Reprinted 1943, 1959.

Trans. with A.G. Sisco, Lazarus Ercker, Treatise on Ores and Assaying. Chicago: The University of Chicago Press, 1951.

Smith, Cyril S. and J.G. Hawthorne, On Divers Arts. The Treatise of Theophilus. Translated from the medieval Latin...Chicago: The University of Chicago Press, 1963.

ARTICLES:

"Biringuccio's Pirotechnia," Mining and Metallurgy, XXI (1940), 189-91.

"The Crystallisation of Metals and Metallurgists under Fatigue," Internal Stress and Fatigue in Metals, R. Rasweiler (ed), Amsterdam, 1959.

"Decorative Etching and the Science of Metals," Endeavour, XVI (1957),199-208

"Development of Ideas on the Structure of Metals," Problems in the History of Science, M.Clagett (ed), Madison: The University of Wisconsin Press, 1959. pp. 467-98.

"The Development of Powder Metallurgy," Powder Metallurgy, J.Wulff (ed), Cleveland: American Society for Metals, 1942.

*"Iron and Steel in 1627: The Fidelle Ouverture de l'art de Serrurier of Mathurin Jousse, "Technology and Culture, 2, (1961), 127-147.

"Metallographic Examination of Japanese Sword Blades," A.I.M., Doc. e Contrib. Storia Metallurgia, No. 2 (1957), 41-68

*"Metallographic Examination of...Zinc...from Athens," Hesperia, Supplement VIII (1949), 126-29.

"Metallurgy and Assaying," A History of Technology, Charles Singer, et.al., (eds), Vol. III, Chapter 3. Oxford: Oxford University Press, 1957.

"Reply to Criticism of E.M. Burgess," Technology and Culture, (I (1959).

"Seventeenth Century Brass Making," Metal Industry, LVI (1940, 285-87/289-291.

"A Sixteenth Century Decimal System of Weights," Isis,XLVI (1955),354-57.

"Science and Art in the History of Metallurgy," Midway, (July 1961)84-107.

"Interaction of Science and Practice in the History of Metallurgy," Technology and Culture, II (1961) No. 4.

"Notes on a Romanesque Reliquary," (with M.C. Donnelly), Gazette des Beaux Arts, (July, 1961), 109-119.

"Note on the History of the Widmannstatten Structure," Geochimica et Cosmochimica Acta, 50, (1962), 971-72.

"Chronology of Metals and Metal Working to 1900 A.D.," Encyclopedia Britanica, (1961 Ed.) and Metals Handbook, ASM, Vol.1 (1961), 43.

"An Early Testing Machine," A.S.T.M. Bulletin, C (1939), 13.

"Metallurgy of the Renaissance,"Technology Review, XLIII (1941), 155-57

"Methods of Making Chain Mail; a Metallographic Note," Technology and Culture, I (1959), 60-67.

*with others