COLONEL A. G. MATHEWS: Thank you very much, Dr. Miller. It is a very distinct privilege to tell you, who have been so marvelously effective in mapping operations in the past, just what we think, our present thoughts.

I. *Introduction.*

Before Pearl Harbor, this nation was so inadequately supplied with maps that we could not plan or execute combat operations in any of the areas in which we subsequently fought. This same deficiency existed in approximately 80% of the area of our own United States. Despite this unpropitious beginning, suitable maps were supplied to all of our military operations during the war. This was accomplished by the use of many tools and methods, the most important of which was photogrammetry. Without the information furnished by photogrammetric methods, those operations necessarily would have been based on inaccurate and insufficient data and would have led to extreme expenditures of national effort and lives. Thus, photogrammetry provided tools and techniques essential in achieving the victory.

It is appropriate at this time to digress to record briefly the gratitude of the armed forces for the effective efforts of the members of the American Society of Photogrammetry, both in developing these tools of victory and in using them for that purpose. Over the long, lean years of peace, despite discouragements and lack of funds, the members of that Society developed equipment, established cadres of technicians and equipment, and kept alive and progressing the science and practice of photogrammetry. During the war you did more than that. You shouldered magnificently the well-nigh intolerable burdens of 24-hour operation imposed by the war upon the facilities under your direction and upon your own unique skills and abilities.

II. *Purpose and Scope.*

It is the purpose of this paper to review the part taken by photogrammetry in the production of maps for the planning and execution of the recent military operations. The subject is treated from the over-all viewpoint of the wartime task of production of maps by all means. The better to understand the part taken by photogrammetry in the war, a description of the whole map production picture is presented. Many unique problems and difficulties were encountered, not paralleled in peace time practice. Because of the limitations imposed by these circumstances upon the application and effectiveness of photogrammetric techniques, these differences will be described, and the conclusions from these experiences summarized as a guide for future development and production.

III. *Magnitude of Mapping Effort.*

The areas involved in our military mapping effort included all varieties of climate, topography and mapped conditions. Climate and topography are mutually geared together, of course. Certain operational areas were the best mapped in the world, while others were blank spots even in the imagination of gossipy travelers. The extreme fluidity of the military situation rendered inevitable frequent and major changes in both strategic and tactical plans, thus necessitating parallel changes in the program of map production. Typical of this was the cancellation of scheduled operations on Mindanao and the substitution of landings on Leyte. We had twenty-eight days, as I recall it, to compile the maps, produce them, ship them, and deliver them to the landing barges.

In all cases, however, regardless of the situation, the demand for accurate, up-to-date maps was immediate, pressing, and enormous. Some criterion of the

scale of effort may be obtained from quotation of admittedly incomplete figures. For the purposes of air navigation, the Aeronautical Chart Service, U. S. Army Air Forces, charted over ten million square miles of the earth's surface. For operations on the ground, the Army Map Service produced and distributed over 450,000,000 copies of approximately 38,000 different topographical maps. That would be a stack of paper about 297 times the height of the Washington Monument.

The Hydrographic Office, U. S. Navy, the Hydrographic Office, Royal Navy, and the Directorate of Military Surveys, War Office, London, were comparably engaged. Over 25,000 American and British troops were employed overseas in making, revising, reproducing and distributing maps for ground forces.

IV. *Fundamental Differences from Civil Mapping.*

Military mapping operations differ from civil mapping in certain fundamental respects, an understanding of which is essential background in the present discussion. The usual topographical map for civil use can hardly be published for specific employment, but must answer most of the general purposes for which maps are required over the course of the years. On the contrary, the military map is pin-pointed for a predetermined time and use. Faulty information on a civil map is generally susceptible of correction before or during use, and in the worst case, leads only to duplication of effort and wastage of time and money. Faulty information on a military map always means excessive loss of life and possible national disaster. The military map must be made despite lack of possession of the ground to be mapped. Colonel Cullen has emphasized that, too. There is hostile resistance to the gathering of the data. They do not welcome the surveyor in back of their lines. There is also the extreme urgency of need and the shortage of time. The allowable inaccuracies of the military map must be less than those of the most accurate weapon that will use the map. So, if we keep our allowable errors less than the probable error of the field artillery piece and of the field artillery survey instruments, we are answering all purposes for which a military map should be drawn.

V. *Corollary and Related Differences.*

Deriving from the foregoing fundamentals are important matters which must be taken into consideration in reviewing the past accomplishments and in planning for the future. Like an egg, a military map is best when freshest, so that provision must always be made for last minute revision. The scale of the map required for military operations is dependent upon the degree of hostile resistance to be encountered—the greater the resistance, the larger the scale of the map required. Since the ability of the enemy to resist cannot be determined precisely six to eight months in advance at the inception of the production program, provision must be made to furnish all maps at all scales.

May I illustrate that just a moment. When Patton broke through on the Normandy front, we had 1:25,000, 1:50,000, 1:100,000, and 1:300,000 scale road maps. About the only thing that Patton used after the break-through, when winding up into the Falaise Gap, was road maps. He didn't want the 1:25,000. He didn't need them.

In combat, a map is useless unless delivered to the predesignated individual combatant who needs that particular map at that specific time and place. Last-minute changes in tactical deployments may render obsolete the previously accomplished distribution so that an entirely new distribution must be completed before the assault.

It is obvious that map operations must be integrated completely with the planning and execution of combat operations and that facilities must be set up as far forward as possible for map revision, reproduction and distribution. Some idea of the magnitude of the distribution task may be derived from the fact that in an ordinary assault, usual last-minute distribution requires over 15,000 copies of each larger scale map to be delivered to a like number of precisely designated individuals in the dark and without transportation. In some instances, certain key sheets were supplied in quantities from 124,000 to 144,000 copies. That was in the Pacific, where each of about eight different bases had to be completely supplied for the entire map effort of the assault on Japan, because we did not know from which of those bases the final mopping up would be accomplished. So, every one of them had to have complete coverage.

VI. *Procurement of Photography.*

One of the two fundamental field operations upon which all subsequent map production must be based is that of procuring the mapping photography. In war time this operation is full of complexities not paralleled in peace time mapping. The usual handicaps of weather and other causes of poor visibility are immeasurably complicated by distance and the unwillingness of the enemy to tolerate our mapping planes overhead. The straight, level flight at mapping altitudes of the photographic plane makes that plane an ideal target for the enemy's anti-aircraft weapons on the ground and for his fighter planes in the air. Any evasive action by the mapping plane as a counter to hostile action interrupts the continuity of the mapping flight and raises screams of anguish from multiplex operators. In many instances, circumstances required our mapping planes to operate at such long range from their bases that they had to be stripped of armor and armament in order to increase gasoline capacity and range. Such stripping increased the vulnerability of the mapping plane to hostile aircraft.

Since our rate of advance was extremely rapid in many areas and maps take from four to nine months to produce after photography has been obtained, it was necessary many times to obtain the mapping photography at extreme range from our front lines. This meant that the mapping planes had to be located at the most forward airdromes. At these bases, the photographic units were in competition with tactical units for airdrome space and facilities, and for tactical and logistical support. You didn't know whether to spend your gasoline for photography or for bombing missions. That was particularly true in China. At such bases all of these items were not only critical but urgently needed for the next day's fighting. Mapping missions were not concerned with the immediate battles, but with providing information so that the map makers might produce topographical maps for possible operations tentatively scheduled for the future. Commanders and staffs of advanced air and ground elements were at close grips with a determined and frequently not too unsuccessful enemy, and had urgent needs to insure the success of their battles then in progress. The most pressing of those needs was the up-to-the-minute information as to the enemy's strength, placement and intentions, and for the evaluation of the effectiveness of our own operations. Consequently, local leadership was always faced with the necessity for on-the-spot decisions as to whether to use their assigned photographic aircraft for mapping missions, for reconnaissance missions, or in some cases, for bombing missions. It was demanding a great deal of a hard-pressed commander then engaged in an all out three dimensional melee with the enemy to expect him to jeopardize his men and his immediate local success for the benefit of a nebulous future project which might never eventuate.

All of these factors, peculiar to war, placed an extremely high value on any mapping negatives which were obtained. This value was so high and the chances of subsequent loss so great that in the spring of 1945 an entire army topographical battalion was stationed well forward in the Pacific, actually at Guam, with the primary mission of receiving, evaluating, plotting, and forwarding mapping sorties and information thereof. It was a big job. It took lot a of men. We had the Navy carrier-based photography. We had the B-29 photography. We had the Fourteenth Air Force photography. It was essential that we not duplicate, because every time you put a man over hostile territory he might not come back.

VII. *Quality of Photography.*

For very obvious reasons, peace time specifications for mapping photography had to be relaxed during the war. For equally obvious reasons, there were many mapping sorties flown during the war which did not satisfy even these relaxed war time specifications. In many instances, such unsatisfactory material was the only coverage obtainable over areas where maps had to be produced. As a result, mapping accuracies decreased and man hours per square mile spent in compilation increased. Many expedients and shortcuts were devised and tried to meet this situation. Some of them were successful at one time; others at other times. Because of the desperate need, something usable had to be made from materials theoretically useless.

VIII. *Accuracy of Resulting Maps.*

Due to these matters, the pressure of deadlines, the lack of control, and the circumstances of photography and compilation, some of the photogrammetric work accomplished during the war should not be regarded as proper examples of either the accuracy or speed of photogrammetric techniques when applied to proper materials.

Despite these difficulties, however, we found that our large scale maps of the Cherbourg Peninsula, stereo revisions of the hachured 1/80,000 Napoleonic maps, were so accurate that our own field artillery were able to use them for unobserved firing by map coordinates. It was also found that the German artillery used our maps in preference to their own. Yet they had been on the ground there for four years. In another instance, in advance of the landings on 6 June 1944, a number of possible airfield sites in France were surveyed from the air and earth work quantities on 157 of these were computed entirely by stereo means.

IX. *Methods Used.*

All tools and techniques of photogrammetry were applied during the war. To name these is to read the catalog. Information was furnished troops in all forms, conventional maps, photomaps, controlled and uncontrolled mosaics, gridded and ungridded vertical and oblique photographs. These experiences in both new and revision mapping by photogrammetric means were so diverse and the problems encountered were so varied that any expert with a fixed opinion can find ample justification for any particular theory he may be selling.

X. *Multiplex Effort.*

It is believed that although no one method proved superior or inferior to the others except in certain cases under certain limiting conditions, our equipment for multiplex operations comprised by far the largest photogrammetric element. Overseas we had five photomapping companies and four photomapping platoons

all equipped with wide angle multiplex projectors and ancillary equipment totaling 684 projectors, with a theoretical monthly capacity of 12,400 square miles, on three-shift operation. In the United States, the U. S. Geological Survey, with 295 wide angle multiplex projectors, had a theoretical monthly capacity of 5,000 square miles. We also had the very fine facilities of the TVA at our disposal and, guessing again, they had about 66 wide angle multiplex projectors and a theoretical capacity of 3,000 square miles per month. Unfortunately, these three lots of equipment differed in internal details, each requiring a diapositive which did not fit either of the other lots of equipment. This lack of interchangeability of diapositives imposed great handicaps on the mapping operation, causing wastage of time and inability to concentrate all facilities so as to complete work in the shortest elapsed time. The only way in which this could have been obviated was to have made three differing diapositives from each mapping negative. The volume of work was so immense and the lack of facilities and force so stringent that this expedient could not be adopted. The rapid changes in combat plans in this war were such as to make interchangeability of diapositives highly desirable. Future wars may find this an absolute essential. The Army will wind up with over 1,200 wide angle multiplex projectors, all of them in use.

XI. *Stereo-Production.*

Many thousands of man hours of time were spent in stereo work which was never completed. We were having to do a lot of crystal ball gazing in our map production program. Part of this was the enemy's fault, as the resistance expected did not develop or the position was by-passed without action being necessary. These matters contributed most materially to the apparent inability to realize the full theoretical capacity of the multiplex equipment. Disregarding many hundreds of thousands of square miles of work partially completed and cancelled because of changes of plan, the U. S. Geological Survey stereo compiled 610 new maps covering 59,900 square miles and photo revised 298 sheets covering 27,000 square miles. That was foreign mapping. They also did quite a bit of domestic mapping, but I am confining my stereo remarks to the war stereo. The TVA stereo compiled 384 new maps covering 39,376 square miles. The Soil Conservation Service, the Forest Service, the Aero Service Corporation, Fairchild Aerial Surveys, Aero Exploration Company, Kargl Aerial Surveys, and Standard Aerial Surveys also made smaller but highly important contributions to the foreign mapping program. Production figures from the troop units overseas are not yet in quotable form.

XII. *Types of Maps Produced by Photogrammetry.*

Photogrammetry was applied by these organizations and those in the field to the solution of the following general problems: Small scale aeronautical charts were compiled from trimetrogon photography for air navigation purposes. Similar compilations were used for laying out flight lines and for plotting the results of mapping sorties, using trimotrogon, in other words, as small scale reconnaissance maps. For lack of other coverage, trimetrogon obliques were used in tilted-head multiplex projectors to tie across between flight lines and to fill gaps in the compilation of new large scale maps. Photogrammetric methods were used to compile entirely new large scale maps, and to revise extensively otherwise unsuitable existing large scale maps. In areas where we possessed apparently excellent native-produced maps of the enemy country, such as

Italy, photogrammetric methods were used to check the accuracy of the information shown, as well as to revise them and bring them up to date. In many instances, such holdings of enemy country were available only in 1/50,000's or smaller, so photogrammetry was used to provide the large scale topographic maps required for combat against heavy resistance. Photogrammetric methods were used extensively in the production of maps for amphibious assaults, various expedients and techniques being used to determine underwater depths and beach gradients. Construction project surveys of airfield sites were accomplished by photogrammetric methods. The photogrammetric techniques were also employed in many ways in purely intelligence investigations to determine the enemy's strength, plans, location, and capabilities, as well as to evaluate the effectiveness of our operations against his positions.

XIII. *Needed Developments.*

All the members of this Society are only too aware of the straitjacket of incompatible facts and physical laws which handicap photogrammetric surveying in either peace or war. We recognize that within the framework of these limitations our present techniques and equipment are expedients and workable compromises, rather than final and complete solutions. In terms of the end results to be achieved, further development is needed to enable us: to obtain control data by airborne methods; to obtain mapping photographs or substitutes therefor from extreme altitudes, regardless of conditions affecting visibility, and to eliminate the majority of time now spent in setting up the models for stereo compilation. The most important of the items involved are briefly as follows:

a. Stable film base for mapping film. As far as that goes, for all cartographic and reproduction operations.
b. Photographic emulsions and lesions of extreme resolution ability.
c. Stabilized mounting for mapping camera.
d. Airborne equipment to insure proper flight lines.
e. Airborne equipment for extending precise horizontal control over very long ranges with first order accuracy.
f. Airborne equipment to obtain horizontal and vertical control of each mapping negative with at least fair third order accuracy.
g. Precision mapping camera for extreme altitudes (with related stereo equipment).
h. Method for night illumination of mapping flights.
i. Method of photography through obscuration.
j. Airborne means of determining underwater depths in six fathoms and less.

Some progress has been made already on some of these items. Two methods for long range triangulation have been developed and are about ready for preliminary service testing. Neither of these methods in the present stage of development of the equipment appears to guarantee first order results, but second order results seem fairly well assured. One of these two methods is equally applicable for obtaining horizontal control of the flight lines and of each mapping negative. New equipment for stabilizing camera mounts has just been obtained and is yet to undergo tests. An airborne method for determining vertical control of each mapping negative is in process of development, modification of needed equipment, and setting up first tests. The figure of accuracy of one part probable error in 18,000 is theoretical. Further refinement is required.

XIV. *Conclusions.*

We may therefore conclude that although much yet remains to be done to develop the materiel employed in the photogrammetric operations, we now have in existence an adequate force of trained technicians properly supplied with usable tools, together capable of doing much useful work. We face the first faint stirrings of a possible awakening of this nation to its domestic and foreign mapping needs. We must work in complete harmony to a common end lest those stirrings lapse again into the sleep of the former complete indifference or result in ill considered, restrictive legislation actually harmful both to the science of photogrammetry and the mapping results desired by all of us. The job in the immediate future is immense. The tasks to be performed by each individual agency within the field of its statutory and customary specialities are more than sufficient to occupy fully all the efforts that that agency can bring to bear. In short, the map and map-related needs of this nation are so great that there is more than enough work for every federal mapping agency within the proper field of its activities. There remains, then, the necessity for achieving concert in awakening the nation to its needs and in continuing coordination of effort in achieving the results to supply those needs.

To provide maps for the military efforts of this nation during the war, both governmental agencies and private firms participated in the finest conceivable example of whole-souled cooperation between individuals and between agencies. I speak for the continuation of these personal and official attitudes so that twenty years hence we may look back on the post war period with the same deep satisfaction as we do when we view the past emergency, with mutual felicitation and admiration for the efficient planning, organization, and accomplishments of each of us who were concerned. I thank you.

PRESIDENT MILLER: Thank you very much, Colonel Matthews, for an extremely interesting talk. I am sure there will be people who will want to ask some questions of Colonel Matthews. Are there any questions? That shows that Colonel Matthews covered the ground pretty thoroughly. We are keeping on schedule pretty well.

Our next speaker is Mr. Guillermo Medina, Head Engineer of the Hydrographic Office of the United States Navy. To members of this society of more than two or three years' standing, Mr. Medina needs no introduction whatsoever. Mr. Medina was President of this Society in 1941, and he has always shown and taken a most active part in the affairs of the Society. It was due to his foresight and initiative that the Society of Photogrammetry came into existence. During the war period Mr. Medina has not been able to take as active a part in the affairs of the Society as we would have liked. The reason for that is that his war responsibilities have been very great, indeed. I need say no more than this: He was in full charge of all chart production for the Navy. I have a great privilege in introducing Mr. Medina.

MR. GUILLERMO MEDINA: Members and Guests of the American Society of Photogrammetry: At no time in our history have the American people been as map conscious as in the past four years. It is no secret that, until recently, we have shown but little interest in the matter of having adequate map coverage for our country, a coverage which is absolutely essential not only for the efficient and maximum development of our natural resources and the conservation of our land, but equally as important for our national security.

As the clouds of war grew more threatening, the same state of unpreparedness existed with regard to the availability to us of adequate map coverage of