SIPRE REPORT 3

SECOND SIPRE SNOW COMPACTION CONFERENCE 24-25 MAY 1951

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SNOW, ICE, AND PERMAFROST
RESEARCH ESTABLISHMENT
CORPS OF ENGINEERS, U.S. ARMY

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SIPRE Report No. 3

PROCEEDINGS

SECOND SNOW COMPACTION CONFERENCE

24 and 25 May 1951

Room 906, Post Office Bldg.
St. Paul, Minn.

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ATTENDANCE ROSTER

U. S. Army

Mr. Raymond L. Tolbert, Office, Chief of Engineers, Washington, D. C.
Mr. A. R. Smith, Office, Chief of Engineers, Washington, D. C.
Mr. George Schoolcraft, Engineer Research and Development Laboratories, Ft. Belvoir, Virginia
Mr. Paul A. Beigbeder, Engineer Research and Development Laboratories, Ft. Belvoir, Virginia
Mr. Kenneth A. Linell, Soils, Foundations and Frost Effects Laboratory, New England Division, Watertown, Massachusetts

U. S. Air Force

Lt. Col. Olav Njus, Air Weather Service, Washington, D. C.

U. S. Navy

Mr. D. C. Hilton, Bureau of Yards and Docks, Washington, D. C.
Lt. (jg) W. R. Rogers, Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, California

Canada

Major A. Taylor, Directorate of Engineer Development, Ottawa, Canada
Captain Ian Smith, Directorate of Engineer Development, Ottawa, Canada
Mr. Lorne Gold, Canadian National Research Council, Ottawa, Canada

University of Minnesota

Dr. Richard C. Jordan
Dr. Homer T. Mantis
Dr. Henri Bader
Mr. B. Lyle Hansen
Mr. M. L. Sandgren
Mr. Jerome A. Joseph
Mr. C. S. Bensen

SIPRE

Colonel L. G. Yoder
Lt. Col. A. H. Lahlum
Dr. E. E. Bucher
Dr. R. W. Gerdel
Mr. George O. Guesmer
Mr. M. H. Berg
Mr. Marvin Diamond
Mr. J. A. Bender

Conference Summary

1. Colonel L. G. Yoder opened the conference with a word of welcome and explained the pending move of SIPRE to the Chicago area. A brief summary of the papers and discussion is given below. Many of the papers presented are reproduced in their entirety in the section following.

2. The morning of 24 May was devoted to statements by the various agencies regarding the accomplishments of the past season. Captain I. Smith described the DED activities at Kapuskasing during the past winter (Paper A) and showed a color movie of the trials. Major A. Taylor similarly described the DED activities at Fort Churchill (Paper B). Mr. Paul A. Beigbeder reported on progress made on contracts for the development of snow compaction machines at ERDL (Paper C). Mr. D. C. Hilton described the BuDocks tests made at Camp Hale during the winter of 1949-50 (Paper D). LTJG Rogers outlined the BuDocks accomplishments at Point Barrow during the 1950-51 winter (Paper E).

3. The afternoon of 24 May was devoted to the presentation of papers and discussions on snow classification and instrumentation for snow testing. Dr. Bader described the accomplishments of the University of Minnesota on the basic research on snow compaction and snow classification to date. A discussion on the various classification schemes in use indicated that the organizations in general are obtaining approximately the same types of data. It was indicated that no further suggestions could be made at this time regarding any snow classification schemes. Mr. Marvin Diamond presented the details of a study made on the use of a drop cone penetrometer which has been developed at the University of Minnesota (Paper F). Subsequent discussion disclosed that Minnesota's tests have failed to provide an indication that the drop cone penetrometer was as satisfactory for general use as the ADT penetrometer. Dr. Bucher described in detail the use of the ram penetrometer, which has been employed in Switzerland for a number of years. The conference made no recommendations as to the revision of existing testing equipment or the construction of any new equipment.

4. The morning of 25 May was devoted largely to the presentation of papers on theoretical aspects of snow compaction. Dr. Bader presented a statement outlining a preliminary hypothesis of snow deformation. Dr. Gerdel presented a paper on the thermodynamic problems associated with compaction of snow (Summary, Paper G). Mr. K. A. Linell described the work of the Frost Effects Laboratory, New England Division in producing snow cover maps for the Northern Hemisphere (Paper H). He displayed four slides showing the average snow cover depth at various times of the winter. Mr. Paul Beigbeder presented a brief discussion on electrical charges on particles with reference to snow compaction.

5. The final session on Friday afternoon, 25 May, was devoted to a discussion of future plans of the various agencies. It was indicated that the Engineer Research and Development Laboratories would continue their efforts to develop a snow compaction machine through their contractors and that if any machines were sufficiently far developed by the time of the Kapuskasing trials next winter, the machines would be sent to that point for testing. The Bureau of Yards and Docks are seeking a site in the United States for testing and will probably conduct tests next winter in the Mammoth Lakes Region of California. The Directorate of Engineer Development of the Canadian Army will again undertake snow compaction trials at Kapuskasing during the coming winter (Paper I). Mr. Lorne Gold indicated that the Canadian National Research Council plan to continue experiments for the prediction of load capacities and are also testing tensile strength (Paper J). He displayed pictures of new instruments for the determination of tensile strength and shear which have been devised by Mr. Klein of NRC. Dr. Bucher outlined the organization of the new SIPRE setup indicating that there would be four major divisions of the organization, (a) basic snow and ice research, (b) applied snow and ice research, (c) meteorology of snow and ice cover, and (d) frozen ground and permafrost. Mr. Bender outlined the activities of the library which SIPRE has established and indicated that it is intended to become a center for the exchange of information on cryological subjects. Several suggestions were made regarding the possibility of holding a series of seminars or periods of instruction in the field on experimental work in progress during the coming winter for those interested in snow and ice. It was indicated that another conference on snow compaction in the spring of 1952 would be desirable.

A. DED KAPUSKASING SNOW COMPACTION TRIALS 1951

Captain Ian Smith

1. Brief description of trials. Trials were conducted over an area of level ground exposed to the prevailing winds at Kapuskasing. Snow depth encountered during trials ranged from 22 to 30 inches. The snow during the earlier part of the trials was uncrusted and dry, consisting in large part of old granular grain type. In the latter part of the trials, after two protracted thaws, the snow was heavily crusted and for short periods after each thaw was quite moist. Snow temperature at the bottom level was generally about 28°F and typical temperature gradients were encountered at all times.

2. The trial area was staked out in 30 ft. trial lanes, which were processed according to a schedule of trials involving different combinations of equipment and methods. Data taken included snow grain type and size, temperatures ambient and of the snow at different levels, snow depths, density, hardness, trafficability and free moisture content.

3. Due to an unfortunate series of equipment breakdowns, a long stretch of trial time involving key equipment was lost when the weather was most favorable with low temperatures prevailing. The mass of trials were conducted under moderate temperature conditions which were not representative of those envisaged as being normal in subarctic work. The chief result of this circumstance was that in many cases, it was impossible to achieve degrees of hardness and trafficability which could be expected under normal cold conditions. In some cases adjacent lanes which had been subjected to equal amounts of processing reacted very differently in trafficability trials. The incidence of minor irregularities and the tendency of the trucks to slide off the shoulders of the compacted lanes became exaggerated in importance as the presence of one or more of these in any one lane greatly reduced its performance. For this reason, the snow density measurement was the only one which was considered uniform enough to provide a fair yardstick for the majority of the trials, and most conclusions are based on this characteristic alone.

4. The equipment tested included the following:

Pulvi-mixer
Low pressure variable weight roller
High pressure variable weight roller
Dry heat apparatus
Tooth harrow
Disc harrow
Seaman S.P. pulvi-mixer
Sliding compactor
Plastic mat.

5. The object of this report is to present briefly the results obtained using each of these items of equipment, and the conclusions derived therefrom.

6. Tractor-towed Pulvi-mixer. Presumably everyone at the meeting is familiar with this piece of equipment so a detailed description will not be given except to indicate the modifications. These were:

(a) Improvised chain flail

(b) Manufacturer's chain flail

(c) Manufacturer's hammer flail

(d) Ski mounted

(e) Dry heat apparatus.

7. The pulvi-mixer was subjected to cold trials in the early part of the trial period, both with and without the low pressure roller. Some of the more significant results obtained in these trials were as follows:

(a) In cold processing in the conditions encountered, the pulvi-mixer can produce snow densities of 0.50 - 0.55.

(b) Within the range of snow and ambient temperatures encountered, there was no noticeable effect of temperature on the snow densities produced.

(c) Density jumped to 0.45+ after the first pass and increased very slowly thereafter at the rate of 0.01 per pass approximately.

(d) The pulvi-mixer alone produced densities as high or higher than those produced by the pulvi-mixer roller combination.

(e) The Hammer flail was found best.

(f) The high operating speed was lost.

(g) The time interval was found not important.

8. The higher rotor speeds produced a more homogeneous pulverized snow particularly in heavily crusted snow. Whether they also resulted in more efficient breakdown of the snow grains is now known because of the lack of equipment for microscopic study. Probably the most significant finding is that the roller, apparently, is superfluous when the pulvi-mixer

is the agitating unit. The trailing edge of the pulvi-mixer hood, if bolted down, leaves a smooth surface behind and evidently imparts as much compaction to the snow as would the roller.

9. Dry heat. To apply dry heat, a small canopy was constructed to fit over the open back of the pulvi-mixer hood. In the canopy were mounted five Surface Combustion aircraft heater burners, each one capable of producing one million B.T.U. per hour. The burners were located so that the heat blast intercepted the trajectory of the snow, leaving the flails at right angles. Due to late delivery of parts, it was necessary to make subassemblies and assemble the apparatus at Kapuskasing where workshop facilities were hardly adequate. As a result, the assembly was rough and ready and the full efficiency of the burners was not developed. This was chiefly due to inadequate air supply to the burners caused partly by low blower capacity and partly by poorly laid out duct work.

10. It was necessary to shut off one burner entirely, leaving 4 burners with total heat capacity of 4,000,000 B.T.U./hr. in operation. This output was further cut down by incomplete combustion indicated by the depositing of quantities of carbon in the processed snow. Further, it is now considered that the burners can be located to take much better advantage of the snow agitation pattern within the pulvi-mixer hood. In spite of these shortcomings, the dry heat process resulted in snow densities somewhat higher than those produced in the cold trials. The beneficial effect was not noticeable until about 8 passes had been made, however, densities in excess of 0.60 were produced. It is considered that the number of passes can be cut down by more efficient use of the dry heat equipment, both by increasing the burner output and by locating the burners in a better position. It is considered that the carbon deposit in the snow can be eliminated largely by stepping up the efficiency of the burners through a greater air supply, although it is not considered that the carbon has a deleterious effect since the discoloured snow would soon be covered by new fallen or drifted snow which would provide protection against any possible absorption by the carbon particles of solar radiation with consequent deterioration of the road surface.

11. After a heavy thaw, while the snow was still quite moist, being easily rolled into snowballs with the gloved hands, it was found that the densities produced by cold processing were not noticeably higher than those produced by the same processes in cold dry snow. This result is not reconcilable with the heat results through any available data. No doubt accurate free moisture determinations would indicate some sort of connection, however, we have yet to be given a good method of determining free moisture.

12. Tooth harrow. The tooth harrow was constructed of structural steel sections, and weighed approximately one ton. It had four banks of teeth spaced 2 feet apart with the teeth spaced at 12" in banks, alternate banks of teeth being staggered. The teeth were 1" x 2" bars, inclined at an angle of 45° and having a vertical depth below the frame of 24". Average depth of penetration of the teeth was 20 to 24 inches in the first pass. The harrow in conjunction with the roller produced densities in excess of 0.45+. It is considered that longer processing will increase this figure to 0.50 approximately. The tooth harrow has the cardinal virtue of simplicity, having no moving parts, which means easy maintenance and dependable performance.

13. It is anticipated that the snow compaction process may be divided into two phases:

(a) The compaction of a subgrade to a density of 0.45 to 0.55 using cold processes.

(b) The further treatment of the upper layers together with any fresh snow which may have fallen, drifted, or been deliberately placed on the road. The use of the more complex equipments, such as pulvi-mixers with heat attachments would be restricted to this latter phase. This would entail heat processing only a relatively small quantity of snow, would be more economical and should make possible the production of much higher densities at the surface with consequent improvement in trafficability. The latter phase may not be necessary under good compaction conditions.

14. In a process such as this the toothed harrow could be used to great advantage. It can produce snow dense enough to provide an adequate subgrade. Furthermore, as the first piece of equipment on the ground, it would uncover any hidden obstacles which might be seriously damaging to the pulvi-mixer or other more complex equipment. This would be accomplished at the expense of a few bent or broken teeth which could be repaired or replaced at leisure. If teeth are bolted to the frame, they may be readily removed and replaced in case of damage.

15. The chief disadvantage of the harrow is the difficulty of manoeuvering it in deep snow. This may be overcome by using a lighter construction with provision for the addition of weights if required. Runners could be provided on the back of the harrow onto which the harrow could be flipped for rapid cross country towing. A second disadvantage is the fact that there is no vertical intermixing of snow from different levels and therefore of different temperatures.

16. The harrow will always have to be used in conjunction with the rollers since it does not leave a smooth surface. Adjustable teeth can be provided for greater depth of penetration in deep snow.

17. Sliding compactor. The sliding compactor tested consisted of two pontoon sections modified to provide a tapered nose section and a rectangular rear section. The nose section was much longer and heavier than the rear section with the result that the nose was usually on the snow and the rear section was tipped in the air wherever the compactor was towed. In soft snow a wave of snow was usually built up under the nose big enough to support the nose in its normal position and permit the rear section to contact the snow. This, however, meant that extra weight had to be added to the compactor in order to maintain any given unit load.

18. It was found that the sliding compactor did not produce snow densities noticeably greater than those produced by the roller, and in view of the greater difficulty of handling the sliding compactor, it was concluded that the rollers were a more desirable compaction unit.

19. Variable weight low pressure roller. The 6-foot diameter roller was equipped with extra weights in the form of steel bars which could be added or subtracted as desired. The minimum weight was approximately 2400 lb. and the maximum was about 3900.

20. Trials were performed to determine the maximum weight at which this roller was capable of good rolling action, and further trials were then conducted to determine the value of extra weight in the roller from the point of view of increased densities produced. It was found that at maximum weight, the roller action was only slightly affected. There was a barely noticeable tendency to slide and the bow wave was only a few inches higher than at minimum weight. It was also found that extra weight in the roller has no appreciable effect on the densities produced. The densities produced by the roller at minimum weight were not appreciably lower than those produced at maximum weight. From this it was concluded that the roller should be kept at minimum weight because of greater ease of handling. It was also established that the roller alone is not capable of compacting snow to densities equal to those produced by the pulvi mixer alone.

21. Disc harrow. The disc harrow was tested as an alternative to the toothed harrow. Unfortunately, the disc diameter was so small (24") that the drawbar and axles were always well down in the snow and plowed the snow up ahead. For this reason, it was not possible to give the disc a fair trial. It was, however, tested over hardened strips and it was found that as long as the snow was not deep enough to be fouled by the drawbar and axles, the disc was quite effective, particularly in chopping up hard rough surfaces. For this reason the disc in the 24" size might be considered as a road maintenance item, but a larger disc size must be obtained before it is worthwhile to carry out further trials in deep snow.

22. High pressure variable weight roller. The high pressure roller was 36 inches in diameter, 8 feet long and extra weights were added in a manner similar to that used in the 6' diameter roller. It was discovered very quickly that this roller was unsuitable for use in soft deep

snow. Due to the high weight-diameter ratio, the roller sank deep and plowed the snow ahead of it. When used on shallow layers of soft snow overlying a compacted subgrade, it was found that the roller left a cracked irregular surface behind it caused by overstressing and shearing of the surface. It was therefore concluded that no further development of the small diameter rollers should be undertaken.

23. Seaman self-propelled pulvi-mixer. This machine had pulverizing characteristics as good as or better than the towed model. Its cross country performance however was almost nil. It could not manoeuvre in soft deep snow. This pulvi-mixer must be track equipped to be of value in snow compaction.

24. Plastic mat. Plastic mat was laid over soft uncompacted snow and trafficked. It was able to support loads up to 5 ton with moderate deflections. Repeated shock loads no doubt would cause the deflection to become more pronounced.

25. The mat also provides protection for the snow it covers in thaws. It is not considered however that the mat will be required under normal conditions when snow compaction equipment is available. Its only foreseeable use would be for the protection of roads during thaws and breakup periods, unless it is finally established that it is not possible to build snow runways capable of withstanding the maximum 80,000 lbs. dual wheel load at present envisaged.

25. General notes. There is a serious lack of instrumentation in snow compaction work. It is not considered that any type of scale test heretofore used is of any value in predicting trafficability. The usual type of failure noted was caused principally by the chewing action of the tires of the test vehicles, particularly in spots where excessive torque and spinning was developed.

26. The Proctor needle which was used extensively this year and last year is considered to be valueless in snow because of the irregularity of the results. In many cases the hardness is beyond the capacity of the instrument.

27. The standard density sample was taken from processed snow before it had begun to set by means of a 100 cc sampler. In several cases, densities of lanes which had been established by weighing samples taken with the 100 cc sampler were checked by weighing 6 in. cubes cut from the hardened snow. In most cases the densities as established by the larger samples were considerably in excess of those indicated by the small samples. Since the cube sample is more likely to be accurate than the cylinder sample, it is considered that the small sampler is unreliable, and it is recommended that a larger sampler be produced for future trials.

28. As has been mentioned earlier, free moisture determination is still almost a complete loss. The calorimetric method attempted is not easily performed in the field and is subject to considerable heat and vapour loss while the snow samples are being stuffed into the neck of the thermos flask. No consistent results have ever been obtained using this equipment. This is a sad situation as it is quite possible that free moisture content may be one of the most important factors in snow compaction.

29. The many equipment breakdowns experienced served to underline the fact that simplicity of equipment is extremely important in Arctic work.

30. Mobility remains a major problem. In many cases a tractor with no load other than the operator can be driven through the snow only with considerable difficulty. For this reason, all snow compaction equipment should be designed carefully to provide maximum mobility. Tracks for prime movers and sleigh runners or skis for towed equipments are essential.

B. DED FORT CHURCHILL SNOW COMPACTION TRIALS 1951

Major A. Taylor

1. The field trials of snow compaction equipments and techniques executed by the Royal Canadian Engineers early in 1951 were divided between two localities. The principal development trials were centered at Kapuskasing, Ontario, midway on the Canadian National Railway line between Quebec City and Winnipeg. It was chosen as the most convenient locality where maximum snowfall normally occurs concurrently with low temperature conditions. It is in the heart of the "bush country" with snow conditions typical of this coniferous forest. The Kapuskasing trials consisted almost entirely of processing short strips of snow by a variety of processes.

2. Practical field trials, on the other hand, consisting of the actual construction and maintenance of snow roads, were located in the Churchill area of northern Manitoba, along the west shore of Hudson Bay. Being on the verge of the so-called barren lands, ground conditions both within and without the tree line were both within reach of the trial team. Although Hudson Bay has recently been proven to freeze completely throughout the winter, an extensive "shore lead" is open on either the east or west side of the bay depending upon the duration and intensity of the most recently prevailing winds. For the greater part of the year, the climate is completely maritime, and even in winter this influence is not entirely absent. High, uninterrupted winds occur with some frequency, fracturing and pulverizing the dendritic snow crystal forms almost as soon as they occur, resulting in relatively fine-textured snow, hammered into hard wind slabs and accompanied by the ridges, sastrugi, and other surface features which typify such conditions. Snow conditions are analogous to those which occur on most other flat exposed arctic coasts, as well as to those which prevail for some considerable distance inland.

3. The principal purpose for which the Fort Churchill trials were designed was to augment the technical information emanating from the work going on at Kapuskasing as well as to evaluate the Kapuskasing techniques under the snow and climatic conditions prevailing at Churchill. The snow compaction trials were a part of a broader series of engineer tests involving unrelated equipment.

4. The equipment selected for these tests arose directly out of Kapuskasing tests of the previous year, viz. - the Seaman pulvimixer and the low pressure roller. Test strips were selected within the tree line, on the barren lands, on tidal flats and on the sea ice representing the full variety of snow conditions available within the Churchill area. The pulvimixer was equipped with a chain flail consisting of 120 chains 15" in length (chain dia. 5/8"), and was mounted on skis. Equipment delays resulted from a breakdown of the 100 H.P. motor it employed. The roller was 6 feet in diameter and 8 feet in width, and its weight could be varied between 3175 and 5800 lbs. in 75 lb. increments.

5. Traffic tests involved the use of 3 ton trucks loaded to a gross weight of 9 tons, developing rear axle loads of 11,500 pounds. Although instruments for making absolute hardness determinations were not considered to be satisfactory, the Proctor needle served the purpose of making relative determinations. A more practical evaluation of hardness, viz., trafficability, was used wherever possible. All tests involved treatment by the passage of the pulvimixer followed immediately by rolling. Controllable variable factors were the weight of the roller, the number of equipment passes and the time interval between passes. Recorded data included the density before and after passes, temperatures during processing, hardening and traffic tests, together with relative hardness determination before and following compaction.

6. No difficulty was encountered in compacting snow anywhere in the Fort Churchill area with this equipment when the atmospheric temperature was below +5°F. No troubles were experienced by traffic on such roads while the atmospheric temperature remained below +10°F. The compacted snow densities achieved during these tests were relatively low, between 0.4 and 0.5. Atmospheric temperatures during the period ranged between -30°F. and +15°F.

7. No satisfactory answer arose to the question of the optimum number of passes of the equipment. Contrary to previous experience with the harrow, a long time interval between passages of the equipment appeared to be definitely detrimental, a four hour interval causing trafficability failures in every instance in which it was tried. A treatment interval of less than one hour produced good results, from which the conclusion is apparent that with this equipment, the time interval between equipment passes should be kept to a minimum, and in no case should it be allowed to become greater than two hours. A recommended "curing" period for the treated snow, prior to its being opened to traffic, ranged between 19 and 24 hours.

8. Using the road-making methods here described, the rate of construction of snow roads amounted to 3 miles a 24-hour working day with the equipment at hand and under favourable conditions. Favourable conditions are defined as "terrain open and flat, snow depth under three feet, wind-chill factor less than 2100 and visibility at least half a mile".

9. Perhaps the most interesting feature resulting from these Churchill tests was the method used in the actual construction of the snow road. A twelve mile section of snow road was built 45 miles northwest of Churchill two miles inland from the shore of Hudson Bay near the mouth of the Seal River, across terrain which was for the most part flat and open. Winds are common and of high velocity, such that wind-borne snow was readily deposited in the lee of rocks, hummocks and other obstacles interrupting its free passage. In locating the road, care was therefore taken to avoid such obstacles.

10. To minimize road maintenance, it was decided to construct this road surface by means of a snow fill to raise it above the level of the surrounding snowfield. By this means, the wind and drift swept over the road surface so that it became in fact self-clearing, obviating the necessity of snow fencing. The equipment used involved a pulvimixer, three rollers and five tractors.

11. The build-up process was attained by spacing the initial passage of the tractors at 45 feet apart, across the proposed centre line. After dragging the snow in towards the centre line, it was roughly levelled by means of the tracked tractors. The treatment with the pulvimixer followed, and in turn the rollers. A built-up roadway was constructed having about a 15 foot surface width, usually raising the road surface about a foot above the surrounding snow surface.

12. Great care was taken in smoothing off the snow-fill slopes, which were made no steeper than a 1:5 slope, the shoulder corners being smoothly rounded off. The "build-up" process was accomplished at the rate of 7 miles a day, but the progress on the road finishing was entirely dependent upon the single pulvimixer unit. By using two such units, therefore, the construction progress could have been doubled.

13. The build-up process in detail was accomplished by starting two tractors on opposite sides of the centre line with blades angled towards each other, continuing forward a distance of half a mile. The two tractors were then reversed in direction, continuing to windrow the snow towards the centre, and finally made their third and last pass in the direction of forward movement. The crests of these final two windrows were from ten to thirteen feet apart. During this windrowing process, the contraction in the snow volume (starting with snow of the order of 0.3 density) amounted to 40% or 50%. The windrows were then smoothed over the road surface and were then followed by five passes with the pulvimixer-roller combination.

14. Within thirty-six hours the road was subjected to traffic, including 3 ton loaded trucks, twenty ton loaded sled (moved at 25 m.p.h.) and tracked tractors. One section of the road, a crossing, was subjected to 50 tractor passes a day over a five-week period without ill effects. No failures occurred over any part of the road. Traffic wore down the corrugations made by the rollers, the only evidence of wear occurring on the surface.

15. The speed at which vehicles could move over the road was governed only by vehicle performance. No difficulty was experienced at speeds of 40 miles per hour, and there was no indication of either sidesway or skidding. No evidence of deterioration of the road surface was visible at temperatures of up to +20°F. which prevailed late in the season. The road was built in mid-February and with temperatures as high as +30°F. up to 8 April had suffered no permanent damage. The effect of the heavy traffic to which it was subjected, if anything, appeared to have improved the road and its surface.

16. Two small airstrips, 120 x 3000 feet, were also compacted on sea ice using the same equipment. Using two tractors, one spread the shallow snow over the airstrip surface to a uniform depth and the other handled two rollers. The construction of the strip and the erection of tree markers spaced at 100 foot intervals took 8 man-hours.

C. ERDL PROGRESS IN DEVELOPMENT OF A PILOT MODEL SNOW PACKER

Paul A. Beigbeder

1. Introduction. At the conference here last December, it was stated that the laboratories had under consideration 3 designs of a pilot model snow packer. The following has resulted since that time:

a. One design has been rejected as being impractical from the standpoint of excessive weight and doubtful mobility. This does not necessarily mean that the procedures incorporated into the design are discarded, but that the method of application was unsatisfactory.

b. The other two designs have been approved for fabrication.

c. A contract for fabrication of one design was executed in February of this year, and a second will be processed at the start of the next fiscal year.

2. Background. At the close of the tests at Limestone, Me., in 1949, it was decided that the results were sufficiently indicative to identify the basic principles which should be incorporated into a snow-packing device. These principles were:

a. Pulverization of a higher order than provided in the production model Seaman Pulvi-mixer.

b. The application of heat to the snow particles to produce melting for lubrication and subsequent bonding and to convert the snow into a state of least strength and thereby make it more compactible.

c. Compaction utilizing the principles of omnilateral or confined compression.

3. The physical characteristics of the end item were to be governed by the following requirements:

a. Be capable of processing a swath of snow 10 feet wide and 6 feet deep.

b. Operating speed 1.5 mph.

c. Average density of snow to be processed, 25%.

d. Average snow temperature 0°F.

e. Rate of fuel consumption to provide lubrication and raise snow temperature to 32°, 0.4 gallons per ton of snow handled.

f. Final density required 75%.

4. Design. These performance characteristics were established for the most part by combining the results obtained in the field and in small scale cold room tests. Limits which appeared to be practicable and possible to attain were set up.

5. The first step in the design was to develop a satisfactory pulverizing component. The magnitude of four variables which control the physical characteristics of the snow pack were listed as being dependent upon the efficiency of the pulverizing unit. They are:

a. Particle size.

b. Particle shape.

c. Number of contacting surfaces.

d. Density.

6. The first variable, particle size, may be controlled. Until information is developed concerning the fracturing characteristics of ice particles, control of the second variable, particle shape, must be passed by. The third variable, points of contact, is a product of the first two variables. Density is also a product of the first two variables but its magnitude varies inversely with the increase in pulverizing efficiency in attaining uniformity of particle size. Assuming that the magnitude of the impact force applied to an ice particle of particular size determines the number and size of the resulting fractured portions, tests were made to determine the impact force required to produce the particle sizes desired. It was found that a rotor having a peripheral speed of 110'/sec produced particles varying in size between 50 to 250 microns with an undetermined amount of snow-dust when the cut per blade was about 1/32", larger bites producing a higher particle size. Shape of these particles were generally angular.

7. The selection of two 3-foot rotors for processing a 6-foot depth of snow was governed by the desire to keep engine weights down and to produce a design which could be readily modified to fit less severe width depth requirements. Using the 110'/sec peripheral speed as the criteria to be satisfied, it was resolved that a rotor speed of 700 rpm for 3-foot rotors must be provided.

8. The requirement for imparting the available impact to only a small increment of snow, made it necessary to reduce the proposed forward speed from 1.5 mph to about 1/8 mph.

9. The analyses at this point produced two rotors, one a hammer flail which utilizes the principle of direct impact on small increments of snow and the second, a blade-type rotor which developes a slicing or cutting action. The recommended speed for both rotors being 600 to 700 rpm.

10. The next step in the design was to evaluate the various methods of introducing heat to the snow pack. Preliminary estimates established that the snow would only remain in these machines for no more than 30 seconds. This meant that the method having the best heat transfer characteristics be utilized. Water met this requirement. In comparing the efficiency of the system and equipment required when

using water derived by melting snow at the site, with methods using steam or direct flame, it was concluded that the use of direct flame was more efficient in fuel utilization and easier to adapt.

11. Having stabilized on rotors as the method for agitating the snow and the use of direct flame for providing the heat units, the next step was to determine how the flame was to be produced and where to apply it. The first requirement was limited to the selection of commercially available burners which had the necessary fuel consumption capacities and which could be readily adapted into the makeup of the units without major modifications. Sufficient justification for entering into the design of special burners was not evident until tests had been made with standard commercial items. The satisfaction of the second requirement, location of burner and method of heat introduction, was dependent on the rotor, that is, the flow pattern snow takes in leaving the rotors.

12. It was established during the Limestone tests that in order to apply heat uniformly and as rapidly as possible and to the maximum number of surfaces, the snow particles must be first disaggregated and placed in suspension within either a heated liquid mass or a heated atmosphere. The problem was to direct the flame from the various burners under consideration so that the maximum amount of heat available would be concentrated in the area where the ratio of snow to air was the least. There are several methods which may be used to apply the products of combustion, none of which are backed up by performance records. The heat trials of the past winter at Kapuskasing were of particular interest to the laboratories as a preview of what might be obtained with the burners recommended and the suggested methods of applying the heat to the snow. I might add that the results indicated that so far as the burners were concerned, we were on the right track. The performance of the compacting equipment in the wet-cohesive snow developed during the heat trials last winter did indicate that the designs developed up to that time should be reviewed and modifications made to minimize the packing of the snow within the confines of the combustion chamber and to assure that a continuous snow flow of uniform wetness and density be maintained.

13. In reviewing the preliminary analyses prepared by the various contractors, it became quite evident that the problem of incorporating a feature utilizing the principle of confined compaction, previously mentioned as a "must", has proven more than they could cope with. Had this principle been included in the designs, the problem we now have of devising a method which will provide a uniform flow of cohesive snow would be solved.

14. One of the accepted designs utilizes a track laying unit to develop its compactive force with a system of side retainers intended to produce the effect of partial confinement. The other design utilizes a ponton for the sole purpose of smoothing the snow after it has been pulverized and heated. Its use is based on the theory that maximum density has been attained by providing an ideal snow particle size gradation and the heating has produced the binder necessary to the development of high snow pack strength.

15. In view of the past winter's work, the revisions necessary to improve the anticipated compaction performance of the unit utilizing the track laying component, without going into a major re-design, amounts to changing the frontal aspect of the track and modifying the trailing edge of the combustion chamber to eliminate all abrupt changes in the flow pattern. In the light of the past winter's work, the smoothing ponton or drag compactor, incorporated in the other design, must be deleted from the design and a new principle incorporated. It has been suggested that a powered belt type compactor similar to the track unit in the first design be considered to provide a more positive flow of the wet snow out of the chamber. It is expected that when these machines are tested next winter, they will have been modified to process wet snow satisfactorily. To facilitate answering any questions you may have, it would be appreciated if the item mounted with the blade-type rotor is referred to as Mark I Snow Packer and the hammer flail mounted machine as Mark II.

D. BUDOCKS' SNOW COMPACTION PROGRAM, 1950

1. Introduction. The purpose of the Camp Hale Snow Compaction Program was to develop techniques and equipment that could be used to so improve a natural snow cover that it would become capable of supporting the traffic of heavy wheeled vehicles. Determination of certain snow properties (such as temperature, type, size, density, hardness, free-water content and void ratio) were conducted before, during, and after the compaction proceedings to ascertain the results of the various techniques used.

2. The most important property of a snow surface from a trafficability standpoint is thought to be that of hardness. This property is defined herein as the ratio of intensity of pressure to depth of penetration. It appears that, under the proper conditions of temperature, snow cover having the higher density will also have the higher hardness. Densities were obtained up to approximately 0.6 gm/cc and hardness values sufficiently high to support, with negligible penetration, limited traffic of a 4-ton, 6 x 6 Army wrecker truck. This truck had a maximum tire load of 4000# with a tire pressure of 65 psi. No heavier vehicle was available for trafficability tests. It is thought, however, that the surface was capable of supporting considerably heavier loads.

3. Equipment. The equipment used consisted of the following:

a. 8' Diameter, Variable Weight, Snow Roller

b. Pontoon Barge Drag

c. Seaman's 6' wide Pulvimixer

d. Disc Harrow

e. Herman-Nelson Heater

4. The Pulvimixer, Harrow and Heater were either ski or toboggan mounted, exerting a maximum intensity of pressure of 2 psi. Of this equipment, the roller and pulvimixer were the most effective in producing the most suitable surfaces. The effects of the various pieces of equipment will be discussed in more detail later.

5. Instrumentation. The instruments and tests used were, generally speaking, unsatisfactory. The tests performed and instruments used were as follows:

a. Snow Type and Size performed by Canadian Snow Analysis Kit

b. Snow Temperature performed by Canadian Snow Analysis Kit

c. Snow Density performed by Canadian Snow Analysis Kit

d. Snow Hardness performed by Canadian Snow Analysis Kit and BuDocks Penetrometer and Field Load Testing Apparatus.

e. Free-Water Content performed by BuDocks Apparatus

f. Void Ratio performed by BuDocks Apparatus.

6. The first three of these tests were simple to make and, consequently, the data obtained were quite reliable. The hardness test was reliable in some cases and not so in others. The fact that the same sized penetrating discs could not be used on both the unprocessed and processed snow surface was a serious drawback. Having developed no means of correlating readings obtained by various sized discs, this meant that there was no means of comparing quantitatively the hardness values before and after treatment. This same lack of correlation prevented a hardness comparison in several cases between some of the compaction techniques. Also, the fact that field temperature conditions are so variable makes it very difficult to compare the effects of the various compacting techniques on hardness. The tests for the determination of free-water content and void ratio were too difficult to conduct with accuracy under field conditions. The few data collected is thought to be of very little value.

7. Compacting tests. The compacting tests were conducted under four categories. They were:

a. Application of pressure

b. Application of heat

c. Depth-processing

d. Combinations

The application of heat as used during these tests proved ineffective. The other methods used were simple to carry out, involved non-complicated equipment and produced quite favorable results. Each of these categories will be treated separately.

8. Application of pressure. The effects of the pontoon barge drag and the roller were compared one with the other as well as comparing the multiple pass procedure using each piece of equipment separately. The multiple pass procedure proved advantageous for both the drag and roller. The drag, after 1 pass, increased the density approximately 40%; after 2 passes, 64%; and after 3 passes, 70%. The roller, after 1 pass, increased the density approximately 78%; after 2 passes, 96%; and after 3 passes, 106%. The drag exerted 0.66 $\#/in^2$ on the snow, and the roller without ballast exerted 4.4 $\#/In.^2$. The drag and unballasted roller weighed 11,200# and 9,000# respectively. When the roller was partially ballasted, it weighed 10,600#, exerted about 4.4 $\#/in^2$ and, after 1 pass, increased the density about 100%.

9. The above results show that the roller was more effective than was the drag. They also show that the roller when ballasted was more effective than when unballasted. A matter of considerable interest was the action of the drag and roller on the snow. The drag had a curved bow which penetrated the unprocessed snow to such a depth that

the bow angle at the snow surface was about 28°. According to Canadian tests and Russian analysis, an angle greater than about 25° will cause plowing of the snow. This, in fact, is exactly what the pontoon barge drag did. The roller, ballasted and unballasted, on the other hand, cut a clean trench in the snow and threw up no windrows whatsoever along either side. As preliminary analysis of the action of a roller indicates that the 8' diameter roller could sink into the snow until the central angle subtending the arc of snow contact was about 43° before it would begin plowing the snow. The ballasted roller actually penetrated the snow to such an extent that the central angle was 32°. In passing, it should be noted that the D-6 tractors used to pull the roller and drag had no trouble at all in pulling the roller, but occasionally had quite a struggle with the drag.

10. The hardness data obtained show that the multiple pass procedure when using the roller is advantageous for increasing the hardness. Such data obtained for the drag warrant no such statement. Neither does the hardness data collected show which one of these pieces of equipment is more effective in increasing the hardness.

11. Application of heat. A toboggan-mounted Herman-Nelson Heater having a rated output of 250,000 Btu's per hour was used in the heat experiments. At the speed at which it was towed and the area onto which the heat was discharged, it is computed that each square foot of snow surface treated received 12 Btu's per pass assuming no heat loss. When allowance is made for the compressive effect of the toboggan on which the heater was mounted, the sole evident effect of the application of heat was that the snow surface temperature was changed from +22°F. to 32°F. If, after 2 passes, it is assumed that the full Btu's are applied to each square foot of snow surface, it is computed that the top 3" of snow would be raised 10°. Actually, the full 24 Btu's did not reach the snow surface nor did the top 3" undergo a uniform 10° temperature rise. However, it is thought that the above computations show to a limited extent the effects of the application of heat by this method.

12. It appears, therefore, that the application of heat as used during these tests was ineffective. It indicates that in order for the application of heat to be effective, the quantity must be of such magnitude that it is impractical to use this method. The density property can be improved, within limits, by much more economical means.

13. Depth-processing. The depth-processing tests involved the use of the pulvimixer and disc harrow. The wheels of the pulvimixer were replaced by skis, and the outer discsof the disc harrow were replaced by horizontal conical flotation discs. This arrangement was very satisfactory with the pulvimixer, but quite unsatisfactory with the harrow. The flotation discs on the harrow did not provide sufficient flotation and, as a consequence, the harrow sunk into the snow so deeply that the frame in many cases almost became buried.

Because of this, the effects of the two pieces of equipment cannot fairly be compared. Further tests with a modified harrow must be conducted. In fact, such a harrow was used at the Arctic Test Station, Point Barrow, Alaska this past winter. Lt. Rogers will probably touch upon this later.

14. In comparing the effects of the multiple pass procedure using the pulvimixer, account must be taken of the initial snow depths encountered on the various test strips. As the pulvimixer treats only the top layer of snow, assumed to be 12" in these tests, it is quite evident that the proportion of snow so treated in a shallow initial snow depth is higher than the proportion in a deep initial snow depth. Therefore, if percent density changes were merely compared, erroneous conclusions might be drawn.

15. During these tests, however, the 1, 2, and 3 pass procedures were conducted on strips having approximately 29" of snow initially. A comparison of the density results shows that 1 pass increased the density 29%; 2 passes increased the density 40%; and 3 passes increased the density 57%. An analysis of the action of a pulvimixer has been attempted and the computed percent density increases conform quite closely with those recorded above. Other things, however, do not check as well, so possibly the above check is coincidental.

16. The Russians claim that the primary purpose of depth processing is to increase the hardness. It is impossible to show that the pulvimixer has a greater effect on hardness than pressure from the data collected during this program. Again, the main difficulty is the lack of control over the field temperature conditions and lack of correlation between various penetrating objects. However, the hardness data collected during this section of the test does show that the multiple pass procedure is advantageous as a means of increasing the hardness of a snow cover.

17. Combinations. The final part of the compaction program was to test the effects of various combinations of the different techniques discussed heretofore. As heat was proven so ineffectual during the early stages of the program, it was not combined with pressure under this section of the program. It was, however, combined with the pulvimixer. This combination had no more beneficial effect than did the pulvimixer alone.

18. The use of the pulvimixer preceded and followed by one of the pressure devices produced the most satisfactory trafficable surfaces. Of the two pressure devices used, the roller was the more effective in this combination. It was found, as was to be expected, that it is advantageous to use the multiple pass procedure with combinations also. Percent density increases up to 130% were obtained with 1 pass of the pressure-depth processing-pressure combination and up to about 150% with 2 passes of the same combination. The two strips that were processed by this combination were subjected to limited traffic of the 4-ton, 6 x 6, wrecker truck, having a maximum tire load of 4,000# with a tire pressure of 65 psi. Negligible penetration occurred as a result of this traffic.

19. Conclusions. The conclusions that can be drawn from these tests resolve themselves into a discussion of the effects of the multiple pass procedure, a discussion of the relative merits of the different categories of compaction techniques, and a discussion of the instrumentation used. It can be said that the multiple pass procedure is more effective than is the single pass procedure for increasing the density and in most cases for increasing the hardness. It appears that the use of the multiple pass procedure beyond the third or fourth pass is impractical.

20. A comparison of the density results obtained by use of the numerous techniques tried show that the various techniques rank in the following descending order:

a. Drag-Pulvimixer-Roller
b. Roller-Disc Harrow-Drag
c. Roller (ballasted)
d. Pulvimixer-Roller
e. Roller
f. Pulvimixer-Drag
g. Pulvimixer
h. Pulvimixer-Heater
i. Drag
j. Disc Harrow

The first two listed successfully withstood limited traffic of a 4-ton, 6 x 6 Army wrecking truck. Strips constructed by the other methods were not tested by subjection to traffic.

21. A review of the instrumentation as used during these tests shows the need for much improvement. It also shows the desirability of keeping the number of such field tests to the bare minimum and the type to the most simple. Snow classification, density and hardness are considered the most essential. Possibly, the tests used for the first tow are satisfactory. However, the hardness test is not satisfactory.

22. Recommendations. The results of the Camp Hale Snow Compaction Program call forth the following recommendations:

a. Extensive traffic tests should be carried out to determine the effectiveness of the techniques already developed; said tests to be accompanied by density, hardness and tire penetration measurements.

b. The penetration problem should be extensively studied in an attempt to develop a rational analysis; thereby providing a means for correlating hardness readings obtained by various sizes and types of penetrating tips, and also providing a means for predicting the trafficability of snow surfaces by various types of vehicles.

c. A standard hardness instrument and test should be developed that will function on all types of snow; said test to involve not only unit load, but also depth of penetration.

d. A study of the penetration problem should be carried out under laboratory conditions as soon as suitable artificial snow-making methods are developed; thereby eliminating many of the variables associated with field work.

E. BUDOCKS' SNOW COMPACTION TESTING AT POINT BARROW, ALASKA 1950-51

LTJG W. R. Rogers

1. Snow compaction tests were performed at the U. S. Naval Arctic Test Station, Pt. Barrow, Alaska during March, April and May of this year. Due to manpower commitments to higher priority projects, we were unable to accomplish the extensive tests which had been programmed. At this time we have not been able to thoroughly analyze the data since receipt on 22 May 1951. The tests were aimed towards developing a method of compaction for purely arctic regions. Tests consisted of the following series of equipment combinations for a preliminary survey:

a. Steel Drag at 4 mph
b. Steel Drag and Pulvimixer
c. Steel Drag at 5 mph and Pulvimixer
d. Steel Drag at 6 mph and Pulvimixer
e. Steel Drag at 7 mph and Pulvimixer
f. Steel Drag at 8 mph
g. Pulvimixer, Snow Surface Heater - 8' Roller at .85 mph
h. Pulvimixer and 8' Roller and Surface Heater at .85 mph
i. Pulvimixer and 8' Roller and Surface Heater at 2 mph
j. Pulvimixer and 8' Roller and Surface Heater at 3.1 mph
k. Pulvimixer and Surface Heater and Sheepsfoot
l. Pulvimixer and Pontoon Drag (11,000 lbs.)
m. Pulvimixer and Water and 8' Roller at 1-1/2 mph
n. Pulvimixer and Water and 8' Roller at 2 mph
o. Pulvimixer and 8' Roller

2. Of the foregoing methods, a final roadway was constructed using the four most successful combinations:

a. Pulvimixer followed immediately with 8' roller and allowed to age harden for two hours between each of five cycles.

b. Pulvimixer and surface heater at .85 mph and sheepsfoot roller. Age hardened for two hours between each cycle.

c. Pulvimixer and water and 8' roller. Water distributed at the rate of $.516/ft.^2$ each cycle.

d. Pulvimixer and pontoon drag.

Data collected during these processes consisted of density, porosity, hardness, temperature (snow and ambient), and snow type. Upon completion of the latter tests, speed, weight, and contact pressure data were collected on vehicle trafficability tests.

3. Conclusions drawn from the data seem to indicate that the four methods will give an equal degree of compaction, which tends to the theory that the best combination would be the pulvimixer and roller because of its simplicity. However, the use of water in greater amounts will give increased hardness and compaction. The basic disadvantages to this method, of course, are the problems of developing suitable water sources and hauling facilities. The use of a surface heater in extreme cold

conditions is definitely problematical from the standpoint of determining its effectiveness. Certainly only a comparatively thin depth of heat penetration can be expected.

4. Unusually early spring thaws interrupted the trafficability tests and the limited data accumulated prohibits any assumptions for accurate compaction criteria. Previous opinions regarding the adequacy of pulverization and rolling to produce a trafficable surface have been confirmed. In all methods there was a remarkably close relation in the final density values and similarly with porosity. The mean snow density during the tests was 0.45, while after compaction the mean density was 0.622. Porosity decreased from a meanof 50% to a mean of 35%.

5. Trafficability was obtained using jeeps and a 6 x 6 truck with a low-bed trailer loaded to 52,000 lbs. Two to three inch rutting occurred in all cases where water was not used after 20 passes by either the jeep or truck. Where water had been used in the compaction process, penetration was less than 1/2". Cone penetrometer readings were on the order of 40, whereas for the water processed tests they were on the order of 200. All snow was classified Type H with a diameter of 1/2 mm. Ambient temperatures ranged from -10°C to -34°C; snow temperatures from -10° to -34°; depth of snow, 20". The soil truss was not tested.

F. USE OF THE DROP CONE PENETROMETER

Marvin Diamond

1. Introduction. The drop cone penetrometer was designed primarily to be used in determining a hardness index for various types of snow. A number of tests have been made during the past winter to study the characteristics of the instrument and develop a hardness index. It is the purpose of this paper to discuss the results of these investigations and to present recommendations for further study.

2. Equipment. The instrument consists of a set of cones having vertex angles of 60°, 90°, and 120° and weighing 0.5 kg, a supporting rod 80 centimeters long, provided with a circular base of 3" diameter and a movable arm equipped with a bubble level and trip lever from which the cone may be released. The circular base is attached to a rectangular piece of 1/8" plywood which helps to balance the instrument. The movable arm may be locked at any elevation on the supporting rod. A set of weights, composed of two 0.5 kg and one 1.0 kg and one 2.0 kg, which may be added to the cones, is part of the equipment. Each cone is provided with a spindle by which it may be attached to the movable arm. The height of the cone and spindle is approximately 30 cm and when the spindle is attached to the movable arm and the point of the cone is resting on a surface, the upper surface of the arm will coincide with the zero mark on the rod. The rod is calibrated to 50 cm above and 30 cm below the zero mark. The height of the drop distance is determined by setting the upper surface of the arm, with the cone attached to it, at the desired height on the rod. After the cone has been released, the arm is lowered until it is again attached to the cone and the depth of penetration is then read directly off the supporting rod. For drop distances greater than 50 cm, the arm may be removed from the rod and the cone dropped from any desired height. It is quite difficult to level the arm without the use of the supporting rod and fewer tests were made for drop distances greater than 50 cm.

3. Theoretical Considerations. The dropping of a cone into a snow pack causes a displacement of the snow and the production of a dent. Some compaction of snow probably takes place as a result of the displacement. The quantity of snow which has been displaced is equal to the density times the volume of the dent or:

$$\frac{p^3 \tan^2 (1/2\ \phi)}{3}$$

= density of snow
p = depth of penetration
ϕ = vertex angle of cone

4. For tests on snow of the same density, the volume of the dent (hereafter referred to as dent volume) is equivalent to the quantity of snow which has been displaced. The energy expended by a cone in penetrating a snow pack, for practical purposes, can be considered as equal to the difference in the gravitational potential energy of the cone

due to its height above the earth's surface before it is dropped and after it comes to rest in the snow pack. That part of the energy expended by the cone in overcoming the friction of air can be considered negligible. This difference in gravitational potential energy (hereafter referred to as potential energy) can be computed from the following equation:

$$\text{Potential energy, P.E.} = (d + p)\,W$$

W = load of cone
p = depth of penetration
d = drop distance

5. Results. The snow pack tested in St. Paul was 38.2 cm thick and consisted of five layers of varying density. Three snow packs of varying density were obtained for test purposes by removing some of the overlying layers. In most of the tests, the cones penetrated through two or more layers. Each of the three cones was used alone and with added weights of 1.5 and 3.0 kg and two drop distances of 50 and 25 cm with respect to surface penetrated were used. Table 1 lists the results of these tests.

6. The snow pack in which the cone penetrometer tests were conducted at the CSSL was about 80 inches thick. The upper eight inches of the pack contained a number of thin ice planes which were due to frequent intermittent small snow storms. Below these ice planes was a homogeneous layer of snow about 15 inches thick. Though a number of tests were made for each set of conditions, fewer tests were made for drop distances above 50 cm because of the difficulties in performing the test.

7. Figures 1 and 2 show that for the same load and drop distance, the depth of penetration for cones with different vertex angles are directly proportional to each other. In subsequent tests, it was observed that the most consistent results were obtained when the depth of penetration was at least 9 cm and since the 90° and 120° cone only penetrate to such depth when heavily loaded, it was decided to use only the 60° cone in future tests. The use of only one cone would also simplify the development of a field kit for test purposes.

8. The range of depths obtained for each series of tests is illustrated in Figures 3 and 4 in which each depth of penetration is plotted for the drop distance used. The range of penetration depths is much larger for drop distances less than 10 cm. This is better shown in Table 2 in which the number of tests made for each drop distance has been listed with the maximum range obtained. From this table, it is apparent that the use of drop distances above 24 cm yields more consistent measurements than the smaller drop distances. It is also noted in the charts that the most consistent results are obtained when the depth of penetration exceeds 9-10 cm.

9. It is generally known that snow of the same density can vary in degrees of hardness, this probably being due to the difference in the degree of fusion between ice crystals (hardness). This is illustrated by cone penetrometer tests which were made on an undisturbed snow surface and a snow surface which had been traversed once by an M-7 snow tractor, a half-track vehicle with a displacement of slightly less than one pound per square inch. The two series of tests were made throughout the day in adjacent sample areas and the results which are plotted in Figure 5 indicate that immediately after compaction by passage of the tractor, the cone penetrated this snow to a greater depth than the adjacent undisturbed area but, after thirty minutes, the depth of penetration in the compressed snow was less and remained less than the undisturbed snow. The density of the compressed snow was the same throughout the test period, yet the depth of penetration changed considerably within 30 minutes. This is a good example of the effect of crystal fusion on hardness of snow having the same density. The initially large depth of penetration immediately after compression may be due to the breakdown of the ice bonds between crystals and possibly fracture of large crystals while the small depth of penetration thirty minutes later may be due to the formation of more and stronger ice bonds between crystals or the degree of fusion between ice crystals is now greater than before the snow was subjected to compression. This test therefore shows that the cone penetrometer may be used to measure the degree of fusion between crystals (hardness) in snow.

10. While the depth penetration by the cone may be a function of the hardness of the snow, density of snow will also affect the depth of penetration. This is illustrated in Figure 6 in which dent volume is a linear function of potential energy and the ratio of dent volume to potential energy decreases with denser snow. If changes in the hardness of snow have a similar effect on the ratio of dent volume to potential energy, it may be possible to derive a hardness index for snow from cone penetrometer tests which can be corrected for the effect of density. This will have to be investigated by testing snows of varying hardness and density. The use of the ratio, dent volume/potential energy, includes all of the variables involved in the dropping of the cone such as drop distance, load, and depth of penetration, thereby making it possible to compare hardness of snow computed from different combinations of drop distance and loads after correcting for the effect of density. Such combinations of drop distance and loads will be necessary to cause the cone to penetrate snow of different hardness.

11. The linear relationship between dent volume and potential energy which was observed in Figure 6 is substantiated by the plotting of these two variables in Figure 7.

12. A series of cone penetrometer measurements were made in an effort to determine the influence of diurnal temperature cycles and solar radiation on the depth of penetration by the cone. The results of these studies which are graphically presented in Figure 8 show that depth of penetration increases much earlier in the day under the influence of solar radiation (site B) than where the surface was

protected by intermittent or partial shade (site A). The importance of conducting penetrometer tests under similar exposures and at the same time each day to insure comparable results is indicated by this study.

13. A number of homogeneous snow layers were subjected to both vertical and horizontal penetration tests using the cone penetrometer to measure vertical resistance and the N.R.C. Snow Hardness gauge tester developed in Canada to measure horizontal resistance. The Canadian instrument can be used to measure either vertical or horizontal resistance. The primary purpose of this study was to determine whether the penetration values obtained with these two instruments were sufficiently related so that the data obtained were directly comparable. The snow layers tested were all fairly homogeneous with no ice planes or layers present. If ice planes or layers were present, the vertically dropped cone penetrometer would penetrate through different materials than the N.R.C. Hardness gauge which was used horizontally and the resulting values would not be comparable. Figure 9 is a plot of the data obtained. While the results indicate a similarity between the horizontal and vertical depths of penetration, the results were not sufficiently consistent to permit computation of a conversion factor. More data are required from snow having a wider range of density, hardness and other mechanical,crystallographic and structural properties before we can definitely determine whether such a conversion factor can be computed. The cone penetrometer is a more objective instrument than the N.R.C. Hardness gauge since the results obtained with the Canadian instrument may vary with the speed at which the disc is forced into the snow. The operation of the cone penetrometer is less dependent on the experience of the operator or the technique used than for the Canadian Snow Hardness gauge.

14. Conclusions.

a. It has been shown that the cone penetrometer yields the most consistent results when drop distances greater than 25 cm are used and penetration depths greater than 9 cm are obtained. It has also been shown that the dent volume is directly related to the energy expended by the cone in penetrating the snow pack and the ratio of dent volume to potential energy decreases with increasing density.

b. A relationship appears to exist between the vertical and horizontal penetration depths of a homogeneous snow pack as measured by the vertically dropped cone penetrometer and the N.R.C. Snow Hardness gauge applied horizontally.

15. Recommendations.

a. A series of cone penetrometer tests should be made in conjunction with compaction and vehicular tests on snows of various hardness, densities, and types in an attempt to determine whether the ratio of dent volume to potential energy is usable as a hardness index for use in predicting the trafficability of a snow surface.

b, Tests should be made to develop conversion factors for the various types of hardness testers.

SIPRE TABLE I 4 January 1951

CONE PENETROMETER MEASUREMENTS AND SNOW DATA
ST. PAUL, MINNESOTA

Drop Distance (cm)					50°			50°			50°			25°			25°			25°		
Vertex Angle, Cone					60°			90°			120°			60°			90°			120°		
Load (Wt. of cone + added wt.)Kg.					0.5	2.0	3.5	0.5	2.0	3.5	0.5	2.0	3.5	0.5	2.0	3.5	0.5	2.0	3.5	0.5	2.0	3.5
					Depth of Penetration																	
Depth below surface cm	Layer Thickness cm	Density %	Grain	Layer Temp. °F.	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm
0																						
	3.8		Fine	23.0																		
3.8 Fine Crust					13	23	26	10	17	20	8	12	15.5	13	21	24	7	14	18	7	11	13 *
	3.8	5	Fine	22.5																		
7.6 Ice L (thin)					12	18.5	23	11	14	16	6	10	12	10	16	21	7	10	12	4	7	10 **
	6.4	17	Coarse grain diam.0.5 mm	23.5																		
14.0 Ice L #																						
	17.8	23	Medium grain diam.0.3 mm	27.0	11	20	22.5	8	14	16	6	10	11	11	13	17	7	11	11	4	7	9 ***
31.8																						
Hard snow	6.4	28	Coarse grain diam.0.5 mm	29.5																		
38.2 Grd.																						

Air temp. was 24 F at beginning of test at 1000 and 21°F at end of test at 1500.

#The ice layer at a depth of 14.0 cm varied in thickness from 0.2 cm to as much as 0.6 cm over a horizontal distance of only 8-10 feet.

* First layer penetrated by cone was 3.8 cm below natural surface with fine crust on surface.

** First layer penetrated by cone was 7.6 cm below natural surface with thin ice layer on surface.

*** First layer penetrated by cone was just below ice layer 14.0 cm below natural surface with snow on surface.

Table 2

Summary of Penetrometer Tests made at CSSL, 14-15 March 1951. Tests made on similar snow pack.

Drop Distance cm	No. of tests made	Magnitude of range cm
1	19	2.5
4	6	4.0
9	10	2.8
25	18	1.0
49	17	1.5
81	14	2.0
144	3	0.6
196	3	1.0
328	2	1.0

For drop distances less than 10 cm, there were 35 tests with a maximum range of 4.0 cm.

For drop distances greater than 24 cm, there were 57 tests with a maximum range of 2.0 cm.

CORPS OF ENGINEERS U.S. ARMY

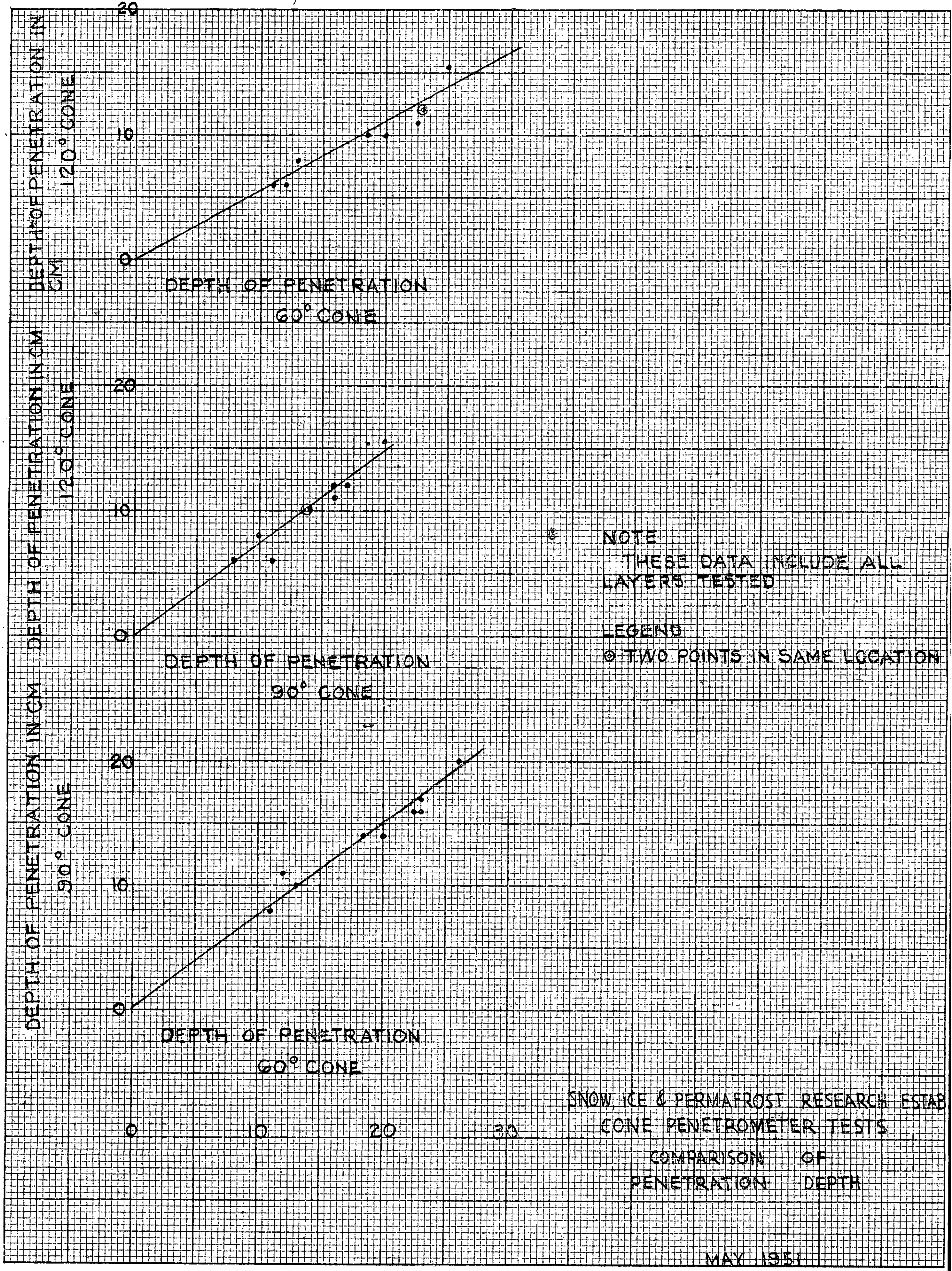
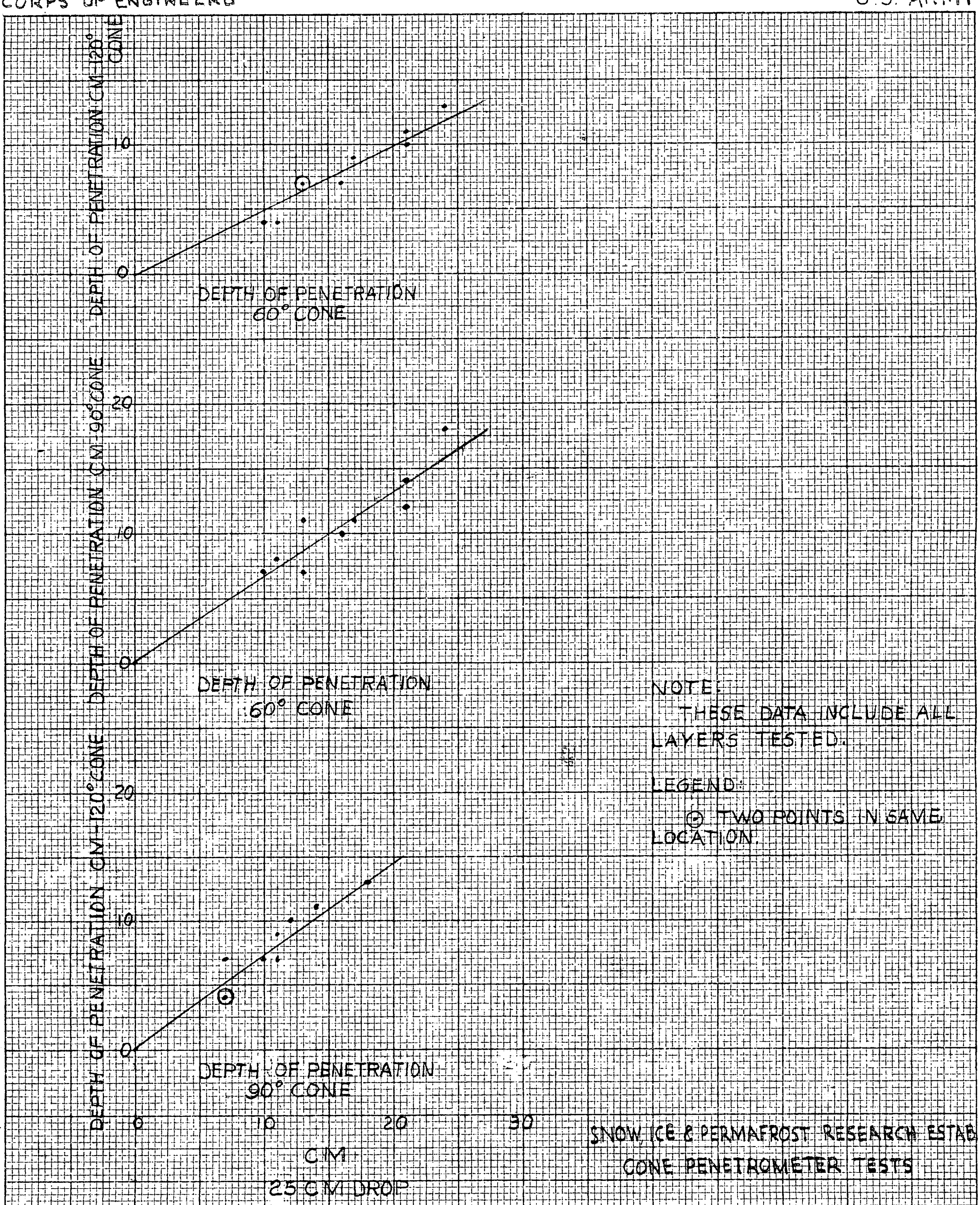


FIGURE 1



SNOW, ICE & PERMAFROST RESEARCH ESTAB
CONE PENETROMETER TESTS

MAY 1951

FIGURE 2

CORPS OF ENGINEERS U.S. ARMY

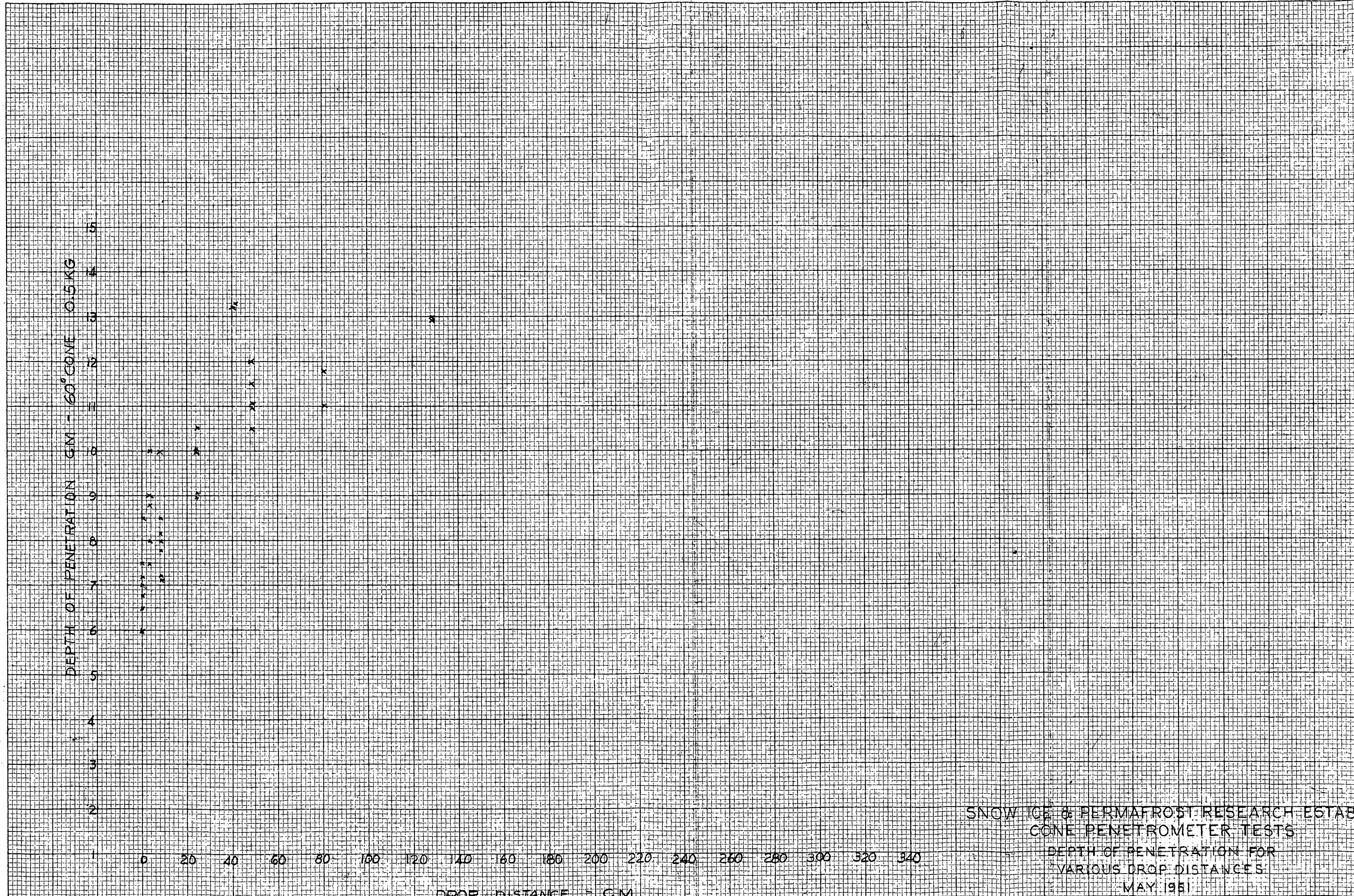


FIGURE 3

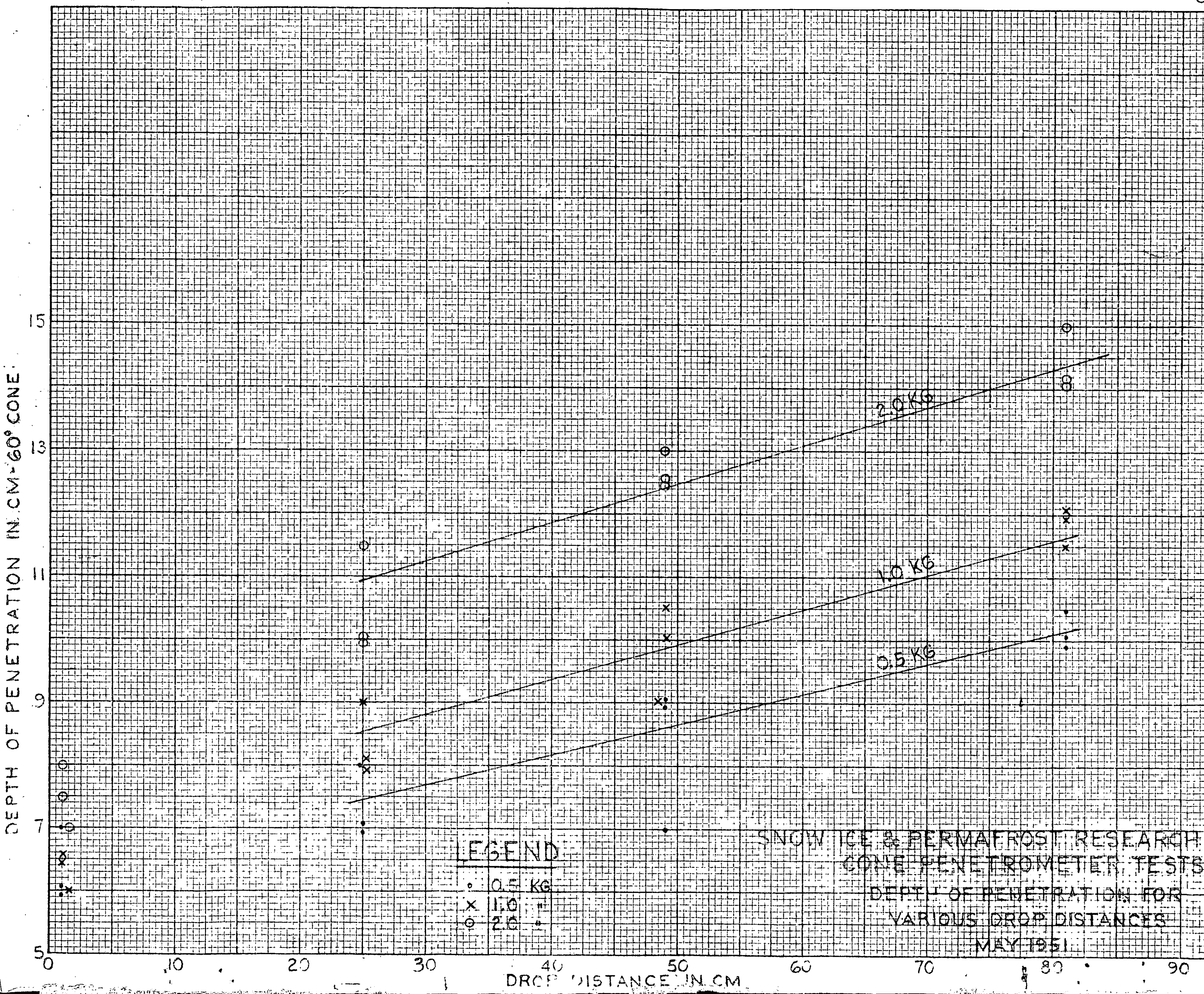
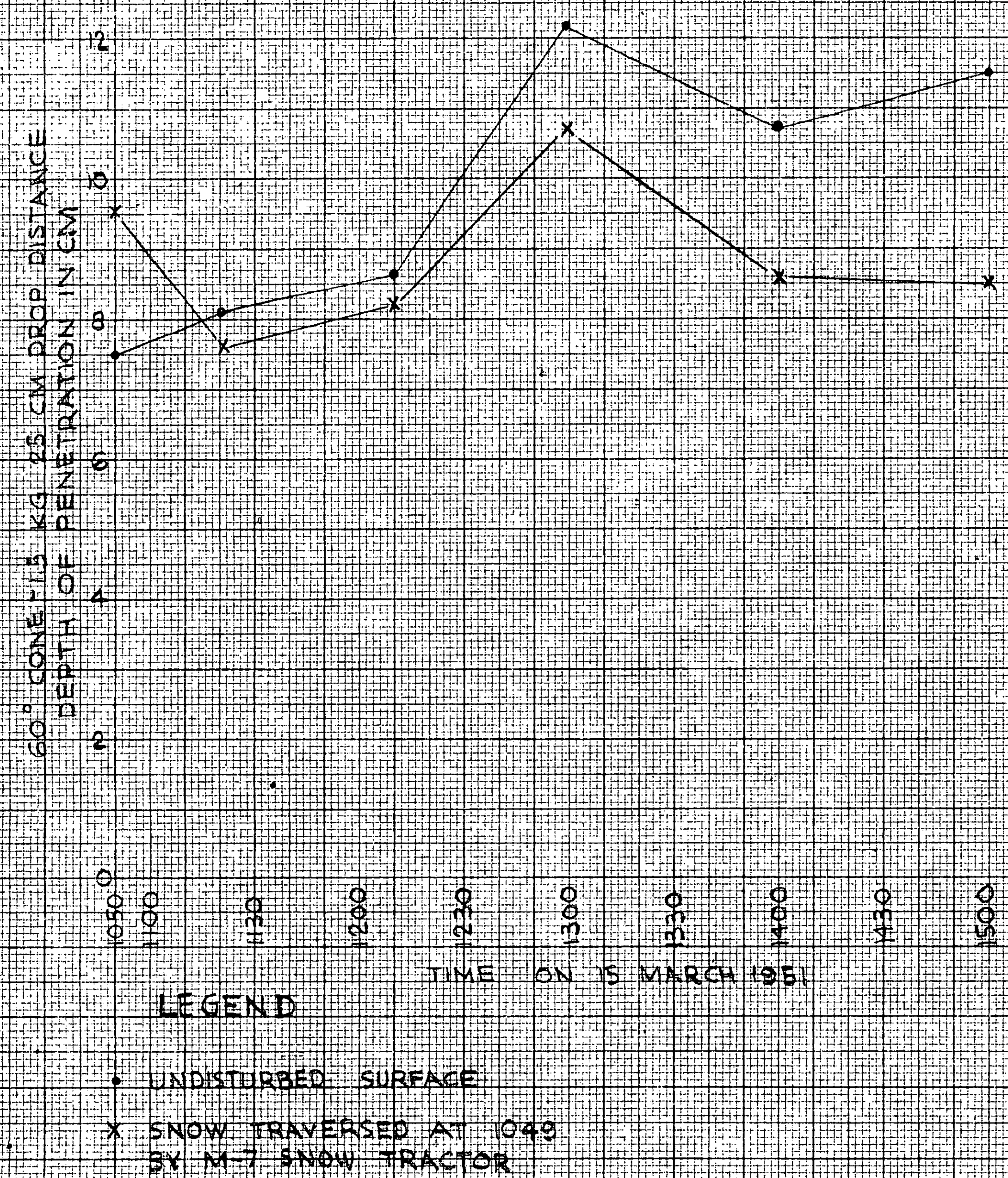

SNOW ICE & PERMAFROST RESEARCH ESTAB.
CONE PENETROMETER TESTS
DEPTH OF PENETRATION FOR
VARIOUS DROP DISTANCES
MAY 1951
LEGEND
• 0.5 KG
× 1.0 "
⊙ 2.0 "
2.0 KG
1.0 KG
0.5 KG
DEPTH OF PENETRATION IN CM-60° CONE
DROP DISTANCE IN CM
5
7
9
11
13
15
0
10
20
30
40
50
60
70
80
90

FIGURE 4



SNOW, ICE & PERMAFROST RESEARCH ESTAB.
CONE PENETROMETER TESTS
COMPARISON OF UNDISTURBED
AND COMPRESSED SNOW SURFACE

MAY 1951

FIGURE 5

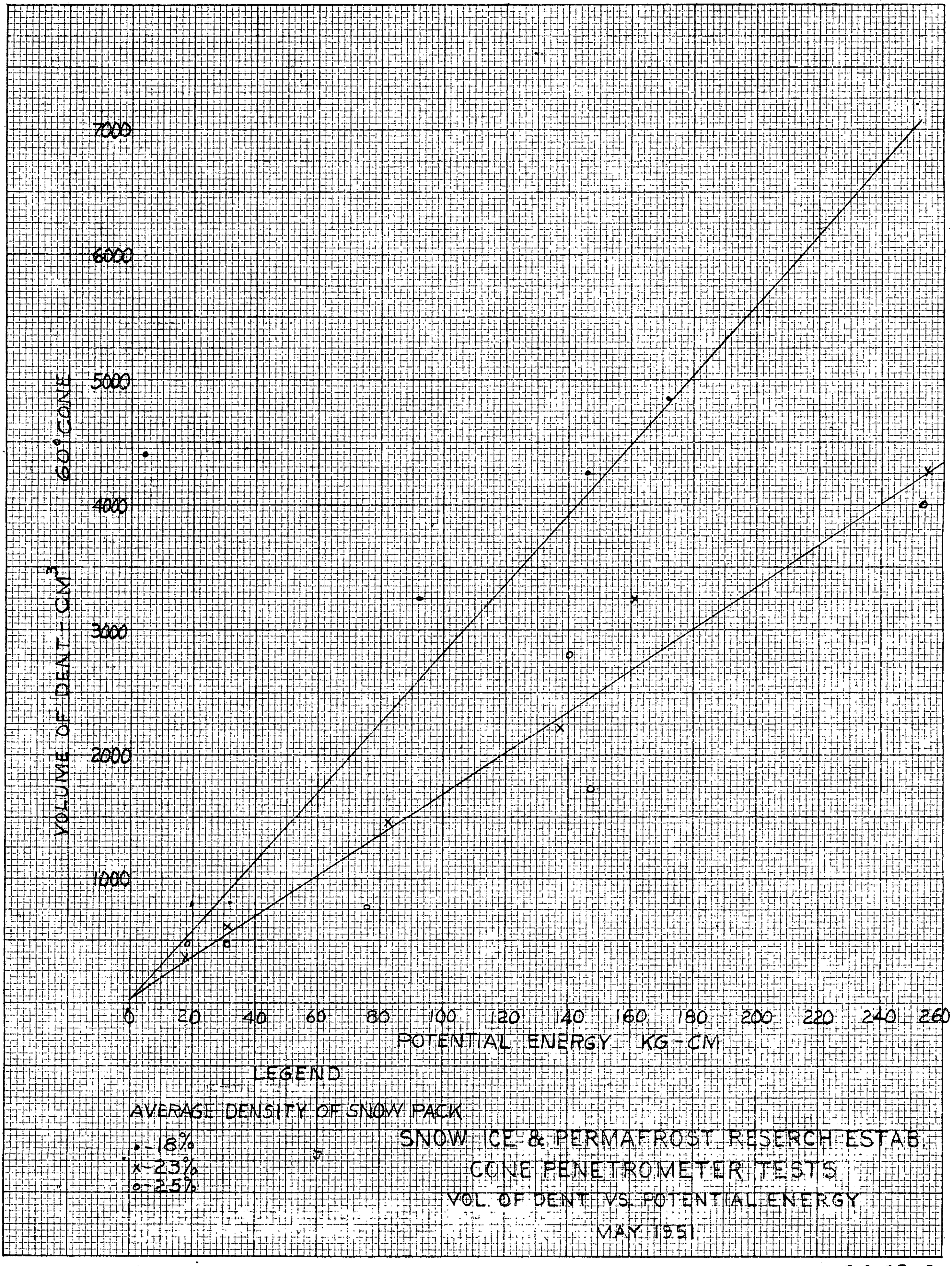
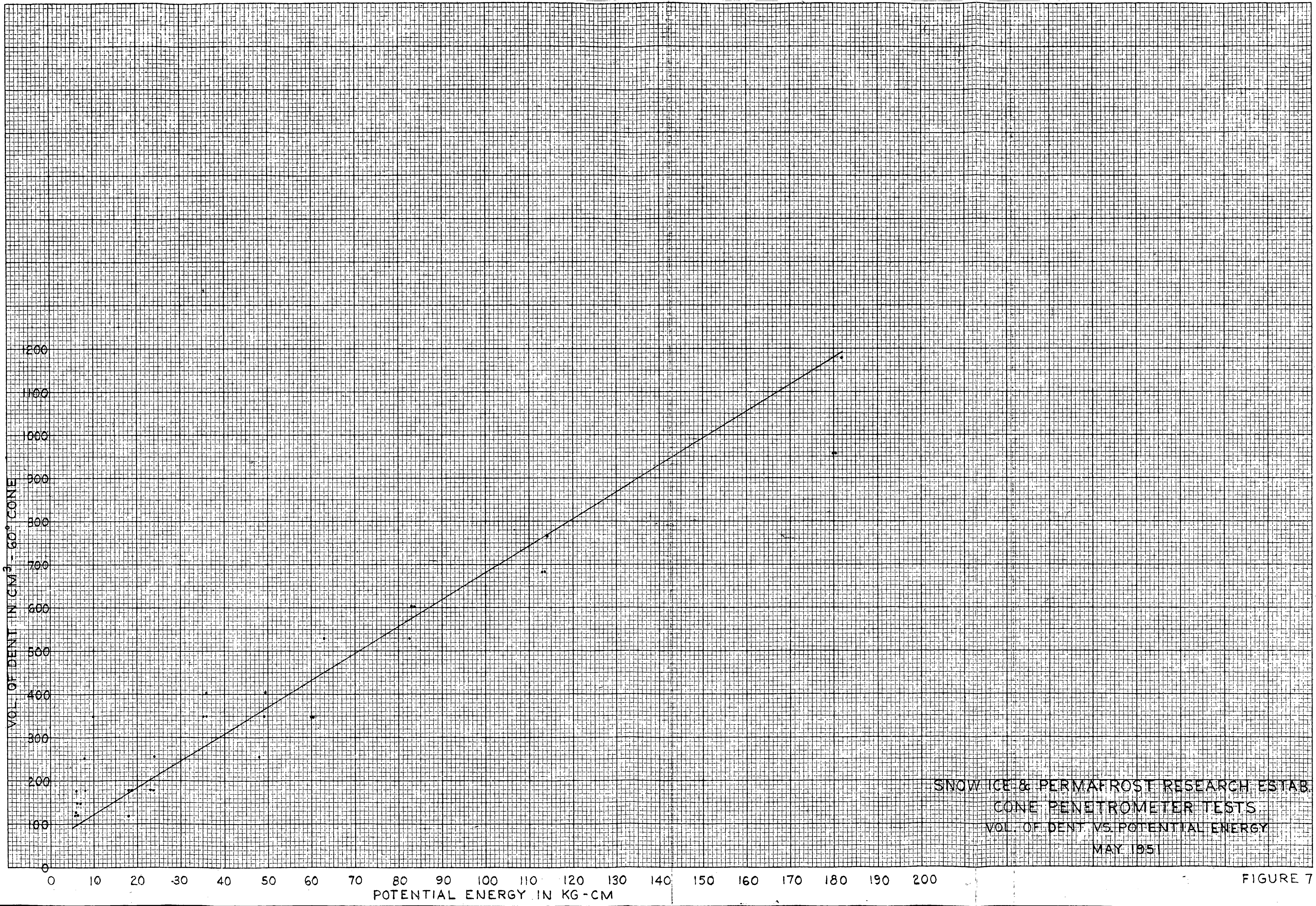
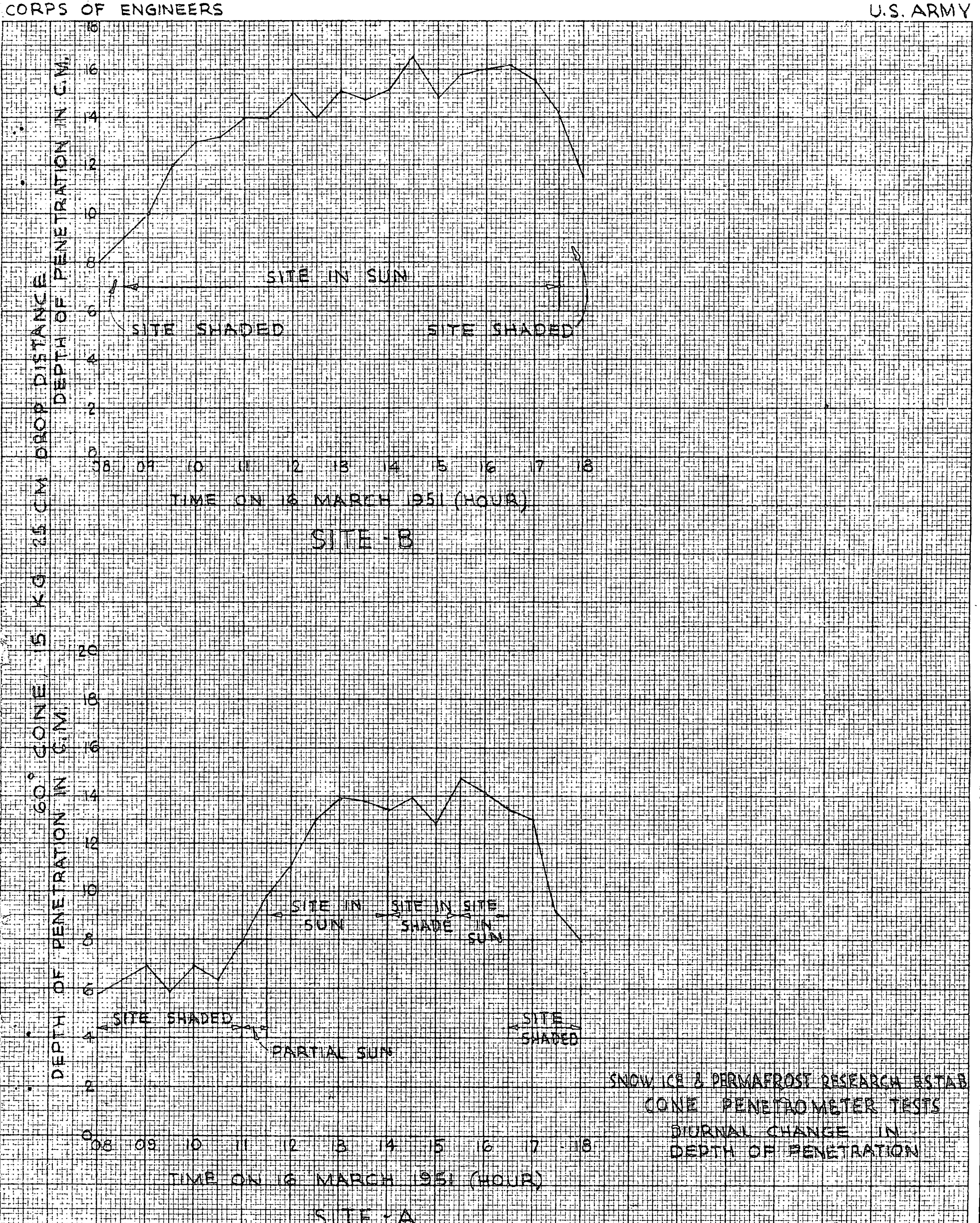

7000
6000
5000
4000
3000
2000
1000
VOLUME OF DENT - CM³ 60° CONE
0
20
40
60
80
100
120
140
160
180
200
220
240
260
POTENTIAL ENERGY KG-CM
LEGEND
AVERAGE DENSITY OF SNOW PACK
•-18%
x-23%
o-25%
SNOW ICE & PERMAFROST RESERCH ESTAB.
CONE PENETROMETER TESTS
VOL. OF DENT VS. POTENTIAL ENERGY
MAY 1951

FIGURE 6



VOL. OF DENT IN CM³ - 60° CONE
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
POTENTIAL ENERGY IN KG-CM
SNOW ICE & PERMAFROST RESEARCH ESTAB.
CONE PENETROMETER TESTS
VOL. OF DENT VS. POTENTIAL ENERGY
MAY 1951

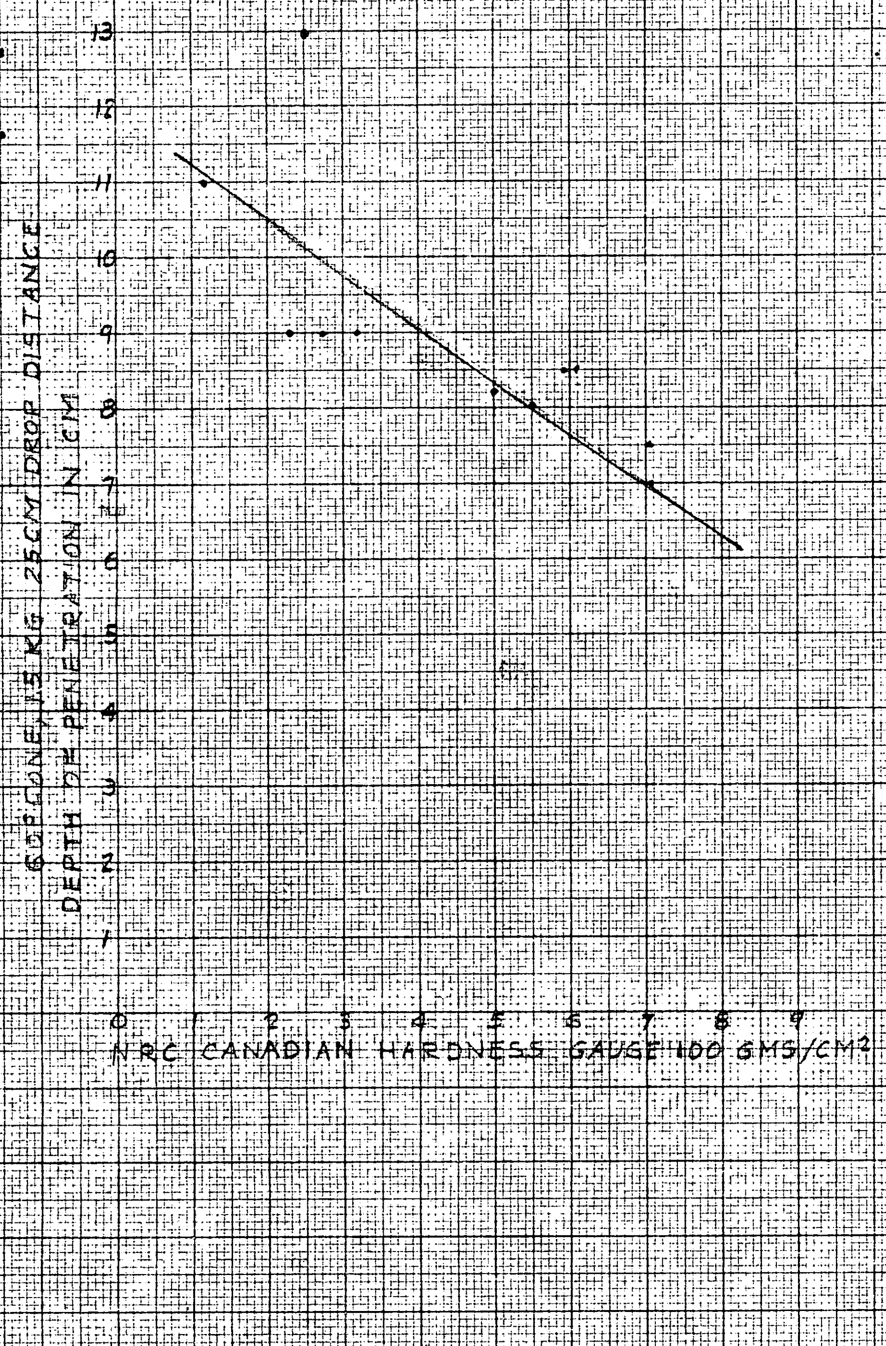
FIGURE 7



SNOW ICE & PERMAFROST RESEARCH ESTAB
CONE PENETROMETER TESTS
DIURNAL CHANGE IN DEPTH OF PENETRATION

MAY 1951

FIGURE 8



SNOW ICE & PERMAFROST RESEARCH ESTAB.
CONE PENETROMETER TESTS
VERTICAL PENETRATION VS
HORIZONTAL PENETRATION

MAY 1951

FIGURE 9

G. THERMODYNAMIC PROBLEMS ASSOCIATED WITH COMPACTION OF SNOW (SUMMARY)

Dr. R. W. Gerdel

The hardening of snow is a thermodynamic process dependent upon temperature cycling, changes in the vapor content within the snow pack, and the energy supplied by sublimation and regelation processes. By means of a hypothetical problem, it was demonstrated that for a 10 degree change in temperature of the snow pack, there was 5 times as much water available for fusion bonds between the crystals at -10°C than at -30°C. This may be considered as indicative of the need for taking advantage of high ambient temperatures and large changes in the ambient temperature when processing and compacting snow. The designer of snow compaction equipment might well give consideration to the hypothetical problem as presented.

H. PRELIMINARY SNOW COVER MAPS OF THE NORTHERN HEMISPHERE

K. A. Linell

1. Snow cover information is needed in planning of ground operations and of landing of aircraft in areas where snow may be encountered. Most of the studies of snow amounts which have been made in the past have related to snow fall rather than snow cover. Amount of snowfall is not a good measure of snow cover conditions because normal snow cover may be light in areas of relatively heavy snow fall if the snow tends to be rapidly removed by winds or thaws, or on the other hand heavy snow cover may develop in areas of relatively light total snow fall if conditions favor its remaining in place and accumulation.

2. The Frost Effects Laboratory of the Corps of Engineers in Boston, in its 1949-50 investigations prepared a preliminary series of snow cover maps of the Northern Hemisphere. The work was done as part of the investigational program of the Airfields Branch, Engineering Division, Military Construction, Office, Chief of Engineers, U. S. Army, under a program whose aim is to develop engineering criteria for construction and maintenance of airfields on ice surfaces. The program has a Restricted security classification. The present brief discussion is given because it is felt that information concerning the depths of snow which may be expected to be encountered in snow compaction operations would be of interest to this conference.

3. In preparing these maps, it was concluded, after some preliminary study, that the first effort should be to rough out a general picture of the snow cover conditions in the Northern Hemisphere through the year which would give an over-all picture and would permit us to visualize and plan how fully-developed maps could best be organized. We wanted to look first at the forest; later we could look at the trees.

4. There seems to have been relatively little attention given to snow cover data in the past. Only a small amount of data was found during our studies which could be used directly. It was generally necessary to extract data, year by year and month by month, from general climatological data publications and to compute the desired average values. The available tabulations were not always in the same form, listing values for periods varying from daily to monthly. It therefore proved to be an appreciable task to extract this data and re-assemble it into the form in which we desired to use it.

5. Because our funds and time were both limited, it was impossible to utilize all the data available and local variations were largely passed over. Several factors influenced the selection of observation stations for plotting on the summary maps. The primary criterion was to obtain coverage of all general areas receiving snow cover during any of the months of the year. Some areas such as the United States, Southern Canada, Northern Europe

and Eastern Siberia provided an abundance of weather station records, and here stations were selected to be representative of the areas and in approximately equal geographic spacing. In other areas including Quebec, Northern Canada and a good part of the U.S.S.R., an insufficient number of data producing stations exist to accurately develop snow cover contours. No data were found for China and Mongolia.

6. We are all aware, of course, that small differences in elevation may cause considerable difference in snow cover. In these preliminary maps our approach was to imagine a global surface passed through the elevations of the observation stations which we had selected. By choosing properly representative stations, we tried to approximate the snow cover characteristics of the general terrain. No attempt was made to present representative data in extremely mountainous regions. By disregarding stations at extreme locations, such as on mountain tops, we believe the results are roughly representative of those general levels of the countryside in which vehicles might operate or on which planes might land.

7. At least ten years of snow cover observations were considered desirable at any one station in order to establish a fairly reliable average figure for snow cover depth for any particular month. It was frequently necessary, however, to use data from stations where observations were available over periods of only three years or less when these were the only available data for the particular general area.

8. The maps were prepared so as to show snow cover depths on the first of each month from 1 October through 1 July. Originally these were prepared with lines of equal snow depth showing 1 inch, 5 inch, 10 inch, etc. depths of snow cover up to 50 inches. For this present discussion, the maps for 1 December, 1 February, 1 April and 1 June have been selected and colored to show those areas having less than 1 inch, (green), 1 to 10 inches (brown), 10 to 20 inches (dark yellow), 20 to 30 inches (light pink), 30 to 40 inches (dark pink), and 40 to 50 inches or more (light yellow). Glacier areas which have snow cover the year round are shown in bright red. For simplicity, all water areas are shown as blue, even though they may be ice covered in arctic areas.

9. On the first slide (#1), we note that on 1 December the 1 inch snow cover line extends from Nova Scotia through the Great Lakes to Southern British Columbia and up to Southern Alaska. In Urasia it swings through Manchuria, outer Mongolia just north of Stalingrad through the Ukraine and swings north toward Estonia and across to Sweden and Norway. The greater portion of the snow cover area on this slide has from 1 to 10 inches of snow cover, but concentrations having up to 30 inches of snow cover have already developed on 1 December along the shores of Hudson Bay and in Northern Siberia. Unfortunately these areas which show highest snow cover are in remote and relatively inhospitable areas so that the number of stations there is very small, and different values at one or two of these locations would change the contours greatly.

10. The map for 1 February (Slide #2) shows the 1 inch snow cover line swinging across New York State south of the Great Lakes to the Central Rockies, and again to approximately the vicinity of Vancouver. In Europe and Asia this line has moved correspondingly farther south in all areas. It will be noticed that very strong concentrations of snow cover appear to exist in Quebec and in two locations in Siberia. The maximum station reading for Quebec being 42 inches, for Northern Siberia being 47 inches, and for the secondary concentration in Manchuria being 22 inches. A single station on Southern Baffin Island at Lake Harbor shows a depth of 69 inches average for this date for six years of record. Again, these concentrations of snow cover are for relatively few stations and the results may have been considerably affected by such factors as methods of observation and peculiarities of the local station position.

11. The map for 1 April (Slide #3) shows relatively little change from that of 1 February although the 1 inch snow contour line has retreated to a position generally a little north of where it was on 1 December, the major change having been in the southerly snow areas. The more northerly snow concentration areas have changed little in snow cover though there has been a tendency for the maximum depths to cover greater areas. (Peak snow depths occurred about 1 March).

12. The map for 1 June is shown mainly for contrast. Here the snow has mainly disappeared except for glacier areas and areas of arctic characteristics. A considerable depth of snow up to 21 inches still persists however, on this date in Northeastern Siberia.

13. These snow cover maps should be viewed with a broad prospective with the realization that wide fluctuations may occur from the average values shown from place to place locally and also from year to year. The values are not precision values. Some measurements may have been made in sheltered wooded areas favorable to snow accumulations, whereas at other stations measurements may have been made in relatively exposed, wind-swept positions. In neither case might the results be truly typical or conditions which would be actually encountered, say, in landings on a nearby lake or river. The contours may also be unduly controlled by one or a few stations which report values which are "out of line", if these are located where the observation stations are widely scattered and they therefore carry higher than average weight. Some of these differences may tend to be averaged out in developing these maps further if data from all the available stations are plotted, rather than the limited number used in these initial maps.

14. Regional maps showing greater detail may be prepared. The effects of altitude, temperature, mountain systems, vegetation, trends of storm paths and other factors may also be given proper consideration in future studies. For such studies it is believed that maps such as have been prepared will serve as excellent planning guides.

15. Maps showing maximum and minimum snow cover, as well as average cover, will be valuable in order that extreme conditions may be anticipated. Maximum and minimum snow cover values were computed for all the stations used in North America and for approximately one half the stations in Europe and Asia, but it was not found possible to assemble the data in map form in the time available.

16. Of equal importance with depth of snow cover are snow characteristics such as density and hardness, insofar as they are measures of bearing capacity of the snow under vehicles or aircraft and of the difficulty of snow handling or removal operations. Since snow cover measurements include all frozen material covering the ground from the lightest, fluffiest snow up to solid ice, it is obvious that information of this type is needed. In Canada, in recent years, as we know, such data have begun to be accumulated.

I. 1951-52 DED SNOW COMPACTION TRIALS

Major A. Taylor

1. General Plan. The 1951-52 snow compaction trials will again be held in the Kapuskasing area, centred upon the airport, subject to the general approval of the Department of Transport. It is proposed to divide the forthcoming program sharply into two sections:

a. Development Section
b. Technique Section

Each section will be in charge of a project officer, and both sections will be under the administrative control of a trial team officer.

2. The development section will carry out a program analogous to the work which has been going on at Kapuskasing over the past two years. It will consist of the development of new equipment and instrumentation relating to snow compaction, with the view of incorporating its use into technical trials of the following year.

3. The technique section will execute trials covering the development of road-making techniques from the reconnaissance stage to trafficability tests of finished snow roads. The equipment to be used will consist of that which was tested in 1950-51 at Kapuskasing incorporating such recommended modifications as are practical to make each item serviceable. From these trials it is required that sufficient data result to permit the final report to be largely directly incorporated into a detailed manual describing the methods, personnel and equipment necessary for the production of snow roads.

4. By setting up the project in these two sharply defined sections, it should become in fact for the first time productive and is organized in such a way that this productivity will be continuous in succeeding years with the least possible delay if this organization is permanently adopted.

5. Development Section. In the forthcoming winter's work, the development section will base its work on a concept of snow road construction which involves the segregation of its construction into two distinct phases - the construction of a subgrade and the construction of a wearing surface. It is felt that the equipment which has been tested over the period of the past two years at Kapuskasing lends itself to certain aspects of each of these phases. The most promising equipment which has been tested to date is undoubtedly the Seaman Pulvi-mixer; its mixing action is much better than may be attained by more simply designed equipments. However, in forcing it through a deep bed of snow, it is felt that we thus impose upon it strains which it was never designed to accept. It is besides a cumbersome equipment to handle under such conditions.

6. It is therefore the intention to investigate more thoroughly the use of a simpler, more rugged implement, viz., the harrow, to create a subgrade of snow in conjunction with the rollers, which have now been found to be satisfactory. Following the hardening of the subgrade, it is the present intention to deal with the top 6 or 8 inches of this partially compacted subgrade with the pulvi-mixer to produce a wearing or pavement surface. This machine will be much more easily handled under these conditions, and will normally be used above the level of stumps and rocks which would otherwise damage it. In this connection, it is intended to explore further the use of the dry heat burner application which gave excellent promise last winter.

7. Technique Section. The other section of the trial team, the technique section, will be involved in working out operational techniques in snow road construction. It is not envisaged that its operation will be confined to the airport area: rather will it be a mobile section producing a roadway during periods of extended absence from the base camp at the airport, probably for a week at a time.

8. The task of this section will begin with the road reconnaissance, utilizing air photos and aerial reconnaissances prior to actual ground location. The equipment used will be improved and modified versions of that which has been tested in previous trials. Construction will follow the methods developed at Kapuskasing and at Fort Churchill, and will involve the application of the subgrade and surfacing concept at an early date. The work will include route marking and maintenance, as well as adequate trafficability trials.

9. The end result of the work of this technique team will be the coordination of equipment and personnel establishments, the finalizing of the technique of reconnaissance construction, anticipated rates of road production under various criteria, and maintenance instructions.

J. CANADIAN NRC FUTURE PLANS

Lorne Gold

1. It is apparent from our observations during the winter that much is to be gained by studying the deformation of snow under an applied load. By employing techniques of two dimensional studies, i.e., snow placed between two parallel transparent plates, a great deal of light can be thrown on the actual mechanism of failure. By studying density variations, it is hoped that the stress distribution under dynamic loading may be determined. Through these studies it is hoped that a criterion for failure may be developed and the dependency of this criterion on density, temperature, crystal size or void ratio determined.

2. Contemporary with these investigations, studies will be made into tensile strength and shear of snow following up the work initiated by Mr. Klein at our laboratories. We feel that the most fertile method of investigation is along lines that have been developed in soil mechanics. This seems especially reasonable in Canada where we are at present interested in being able to transport loads across annual snow surfaces of only a few feet in maximum thickness. Work by Major Bekker and many others has also shown the great simularity between failure in soil and failure in snow.