# EFFECTS OF EXPLOSIVES ON THE MOUNTAIN SNOWPACK

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## ABSTRACT

A seismograph was used in a series of tests to measure the shockwaves produced in the snowpack from the detonation of explosives. Two different explosives commonly used in avalanche work were tested. Different shot placements in relation to the snow surface were compared, different types of snowpack were compared, and different size charges were compared. The results showed that a two pound cast Pentolite booster and a 3x8 cartridge of ammonia gelatin dynamite produced almost identical shockwaves. Air blasts were shown to produce slightly larger shockwaves than surface blasts. While buried shots produced much smaller shockwaves than air or surface blasts. A charge detonated 25 cm (10 inches) below the snow surface produced shockwaves of approximately half the amplitude of a surface or air blast. Ground waves were shown to be insignificant, even when charges were detonated on the ground surface. When comparing different snowpacks, the results show that shockwaves penetrate deeper with less attenuation into a harder snowpack, than they do into a softer less dense snowpack. When comparing different size charges, it was shown that doubling the shot size would approximately double the area that was affected by the shockwaves to the same degree.

## INTRODUCTION

Over a number of seasons the avalanche workers at Big Sky had noticed that explosives were particularly ineffective for releasing avalanches on a certain slide path. This slide path "Snakepit" is different from most other slide paths at Big Sky in that it is below treeline, and therefore exposed to much less wind. Because of this the snowpack in Snakepit is not very dense and lacks any firm layers. Snakepit has a predominantly eastern exposure and it has a relatively warm ground temperature because of geothermal features (Tremper, 1986). The snowpack in Snakepit is usually advanced TG bottom to top until sometime in February .

It was thought that the reason for the ineffectiveness of explosives in Snakepit was because its soft low density snowpack didn't transmit shockwaves as effectively as a harder wind exposed snowpack. The author began looking for a method to measure shockwaves in the snowpack, so the effects of explosives on different types of snowpacks could be compared. The only thing available for the right price was a seismograph borrowed from Montana State School of Minerals and Mining in Butte. Along with comparing different snowpacks the seismograph was used for comparing different types of explosives, to compare different shot placements and to compare different size charges. Shockwaves were recorded from a total of 37 shots.

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Originally it was thought that the longitudinal P-wave could be measured as it is transmitted through the snowpack. But the geophones that were available only measure vertical movement. It was shown from the tests that shockwaves attenuate very rapidly in the snowpack. Because of this the P-wave in the snowpack is negligible except in the immediate vicinity around the crater. Air is a much more efficient medium for transmitting shockwaves. Most of the movement of the snowpack is caused by the sound wave, which is a P-wave, traveling through the air and striking the snow surface, producing a transverse S-wave, which causes vertical movement in the snowpack. So using geophones that only measure vertical movement turns out to be a good way to measure the movement of the snowpack caused by explosives.

## SET UP

A 12 channel seismograph was used, allowing the shockwaves to be monitored at 12 locations for each shot. The seismograph had a firing unit that would detonate the explosive with an electric blasting cap, and simultaneously start the recorder. The results would appear on a small TV monitor and also could be printed out on paper (if this function of the machine is working).

On the first tests the geophones were spaced at 10 m increments from the point of detonation. Even using the lowest settings on the recorder, the amplitude of the waves was larger than what the closer phones could register, resulting in incomplete waves on the monitor. Using the lowest settings on the recorder, with a standard one kilo charge, the waves would attenuate to were they wouldn't register much beyond 100 m. So for most of the tests the geophones were buried at 20 m increments from the point of detonation. Geophones were buried in 5 holes, the closest being 20 m and the farthest being 100 m from the point of detonation. Each hole had a geophone buried just under the snow surface and one buried at the bottom of the snowpack, just above the ground surface. Hole 2 (40 m) and hole 4 (80 m) also had a geophone buried at midpack. So holes 1, 3 and 5 had two sensors each and holes 2 and 4 had three sensors each. The geophones were buried above each other into the vertical side of the holes. The phones were inserted a few inches into the side nearest the point of detonation and then backfilled. The holes were offset in a slight arc, so the waves would not pass over or through the closer holes before reaching the farther holes.

The geophones remained buried in the same locations for one group of tests (5-10 shots). The point of detonation would be moved slightly so the charges had relatively undisturbed snow underneath when detonated. This practice didn't have a significant effect on the results. When the same shot was repeated, the later shot would produce the same or very slightly larger amplitudes. No measurable settling occurred at any of the sensor locations during the tests.

The tests were conducted at Big Sky of Montana. The first tests were in April 1991 in an isothermal snowpack at an elevation of 2500 m. During January of 1992 three groups of tests were conducted. Group A was in the same location as the tests in 1991, but the snowpack was dry with mostly faceted crystals. Group B was in a snowpack similar to group A with dry faceted crystals, but it was somewhat softer and less dense. Group B was below treeline at 2500 m and well protected from the wind. Group C was above treeline at 3030 m and had a much harder, denser, wind effected snowpack.

Charges were detonated one meter above the snow surface, on the snow surface and at different depths below the snow surface.

Most of the tests used either a 3x8 cartridge of ammonia gelatin dynamite or a 2 pound cast booster. The following is a comparison of these two explosives.

|  | Cast Pentolite<br>(TNT & PETN) | Dynamite<br>(ammonia gelatin) |
|---|---|---|
| weight | .9 kg (2 lb) | 1.25 kg (2.75 lb) |
| density | 1.60 gm/cc | 1.43 gm/cc |
| detonation velocity | 7000 m/sec | 6400 m/sec |
| detonation pressure | 220 k bars | 150 k bars |
| energy | 1100 cal/gm | 1050 cal/gm |
| total energy | 997,700 calories | 1,309,350 calories |
| cost | $ 5.25 | $ 3.53 |

Some testing was done using larger charges during the 1991 tests. These included some double shots using both cast and dynamite, and two 6.5 kilo ANFO shots.

## COMPARING DIFFERENT SNOWPACKS

### *Results*

Tests were conducted in four different snowpacks. Snowpits of the four test sites are shown on page 7. (211)

Because the P-wave that is transmitted through the snow couldn't be measured, the only way to compare attenuation rates in the snow was to compare the amplitudes of the shockwaves on the lower sensors, with the amplitudes of the shockwaves on the surface sensors directly above. This comparison is compromised by the denser plug of snow next to the sensors, which resulted from filling in the holes after the sensors were buried. Still, the results agree with Gublers findings (Gubler 1977). In the isothermal snowpack there was substantial attenuation between the surface sensor and the lower sensor in the same hole. In the low density dry snowpacks there was slight attenuation between the surface and the lower sensors. In the higher density dry snowpack of group C there was no discernable attenuation at holes 4 and 5, were the snow depth (approx. 1 m) was comparable to that of the other groups. In holes 1, 2 and 3 were the snow was deeper (2 m +) there was substantial attenuation. Examples of the shockwaves from different snowpacks are on page 8. (212)

### *Discussion*

The shockwave attenuation rate in snow seems to be more directly related to the snows hardness than to the snows density. A stronger harder snowpack would usually build up more stress from creep and glide, than a softer less cohesive snowpack, making it more susceptible to failure also. The snowpack in Snakepit is usually a very soft slab. When it slides to the ground, it sometimes slides as a slab avalanche. But sometimes pockets slide as loose snow avalanches, even though they run to the ground, suggesting very little cohesion.

Why shockwaves attenuate at a faster rate in isothermal snow than in dry snow, might be because in an isothermal snowpack the waves are passing through three distinct densities; ice, water, and air, instead of two, ice and air. Also, the ice grains in isothermal snow are softer and more pliable than they are in a colder snowpack. Warmer softer ice grains would dampen and absorb more of the energy from a shockwave, whereas, a colder harder ice grain would transmit more of the energy to neighboring grains.

## COMPARING DIFFERENT SHOT PLACEMENTS

*Results*

The wave amplitudes of airblasts, 1 m above the snow surface, averaged 10 - 15% greater than surface shots. The results show a major advantage to having the explosive in direct contact with the air, as opposed to being under the snow surface. At 25 cm (10 in) below the snow surface, a charge produces shockwaves of approximately half (50%) the amplitude of a comparable surface or air blast.

For buried shots the amplitude of the shockwaves was proportionate to the distance the charge was below the snow surface. The distance of the charge from the ground had no bearing on the wave amplitudes. Examples of different shot placements are on page 9. (213)

*Discussion*

The results of this comparison also agree with Gubler's 1977 tests (Gubler, 1977). When charges are detonated below the snow surface, the shockwaves lose much of their strength traveling through the snow, before they reach the snow surface, where the waves are then transmitted much more efficiently through the air.

No ground (seismic) waves were recorded during any of the tests. Probably because the control settings on the seismograph were adjusted for recording the much larger sound waves. The gain (amplification) had to be set on zero or the shockwaves would be to big to be discernable on the monitor. The trace size also had to be on one of the lowest settings or the waves would come up too big. When shooting an Avalauncher or artillery (unless a proximity fuse is used) it is best to aim for the shallowest snowpack in the target zone, unless flyrock is a problem. This isn't so the ground will transmit a shockwave, but so the explosion is in better contact with the air, not being muffled by the snow.

Because of the grounds higher density, the ground waves would attenuate at a slower rate than the air waves. So at some point, hundreds of meters, from the point of detonation the ground waves may impart more movement into the snowpack than the air waves. These waves, because of there small amplitudes, would be insignificant under most conditions.

## COMPARING DIFFERENT EXPLOSIVES

*Results*

Most of the tests compared a .9 kg (2 lb) cast booster with a 3" x 8" cartridge of ammonia gelatin dynamite weighing 1.25 kg (2.75 lb). These two explosives produce similar results. The faster detonation velocity of the cast booster seems to compensate for it's lighter weight. When different size charges and other types of explosives were tested it was evident how evenly matched these two explosives are. Cast boosters produced slightly larger amplitudes than dynamite when the charges were detonated 1 meter above the snow surface. When the charges were detonated on or below the snow surface there was no consistent difference. Sometimes the cast would produce slightly larger amplitudes, and sometimes the dynamite would produce slightly larger amplitudes.

Another comparison that was done with these two explosives, was to detonate a charge on the snow surface and measure the resulting crater. A .9 kg (2 lb) cast booster was compared with .9 kg, 1.25 kg and 1.6 kg dynamite charges. On the average the 1.25 kg (standard 3 x 8) charge of dynamite produced the same size (2.4 m) crater as the cast. The .9 kg dynamite charge produced an average crater diameter of 2.2 m, while the 1.6 kg dynamite charge produced an average crater diameter of 2.6 m.

### *Discussion*

Both of these explosives, cast boosters and ammonia gelatin dynamite, have some advantages over the other one. Cold temperatures are not a problem for either one. Dynamites with a high nitroglycerin content can freeze at cold temperatures, making then hazardous if forcibly "punched" to make a capwell under these conditions. Most of today's dynamites, including the ones tested, don't have a high nitroglycerine content. The term "nitroglycerine" is loosely used when referring to "NG" dynamites. All "NG" dynamites contain a mixture of nitroglycerine and nitroglycol. The "NG" content of the ammonia gelatin dynamite tested (which was labeled 60% strength) is 25%. Of this 25%, 90% is nitroglycol and 10% is nitroglycerine. Nitroglycol is usually the larger percentage of the two because it has a lower freezing point, better heat stability, and is less costly. The particular dynamite used in these tests has a freezing point around -65 degrees C (-85 degrees F).

The difference in the detonation velocity of these two explosives (cast 7000 m/sec and dynamite 6400 m/sec) isn't so much when compared to the velocity of the resulting soundwave (350 m/sec), which is responsible for transmitting most of the energy into the snowpack. The author would have liked to of been able to compare the attenuation rates of the P-waves in the snowpack, in the vicinity around the crater, for these different speed explosives. This was impossible without geophones or sensors that could measure horizontal movement.

Advantages of cast Pentolite boosters:
- less weight per shot
- less bulk per shot
- has an indefinite shelf life

Advantages of ammonia gelatin dynamite:
- costs less
- doesn't leave blackmarks on the snow
- can double fuse single charges
- can be cut into smaller charges

## COMPARING DIFFERENT SIZE CHARGES

### *Results*

Two comparisons were made with different size charges. One compares single with double shots (using cast boosters and gelatin dynamite) detonated from the same location on the snow surface. The other compares the waves from 6.5 kg (14 lb) ANFO charges, detonated farther from the sensors, with smaller 1 & 2 kg charges, detonated closer to the sensors.

The ANFO shots themselves, one primed with a cast primer and one primed with a dynamite primer, produced similar results. The one with a cast primer produced 5 - 15 % larger amplitudes.

When comparing the results of two specific shots, the distance from the point of detonation to where the shockwaves of each had equal amplitudes would be used as the respective radius to calculate the area of equal influence for each of the two shots. For the cast, this distance to equal amplitude was 32 m for a single charge and 50 m for a double charge. The areas work out to be 3215 square meters ($32^2$ x pi), and 7850 square meters ($50^2$ x pi) respectively. So by increasing the charge size 100%, the area of influence was increased 144%.

Also, part of the double charges area of influence would have received a greater shock than any part of the single charges area of influence. For gelatin dynamite, it worked out to be an 130%

increase for a double charge (100% weight increase). So a double charge would shock more area, some of it to a higher degree, than would two single charges.

In the other size comparison, the large charge was comprised of, 5.5 kg (12.5 lb) of ANFO primed with a .9 kg (2 lb) cast booster or a 1.25 kg (3 x 8) gelatin dynamite primer, for a total weight of approximately 6.5 kg. This was compared with .9 and 1.8 kg cast charges, and with 1.25 and 2.5 kg dynamite charges.

The method described above was used to calculate the following results: (As mentioned previously a .9 kg cast booster and a 1.25 kg dynamite charge produced equal amplitude shockwaves. A 1.8 kg double cast and a 2.5 kg double dynamite also produced equal results.)

.9 kg cast booster vs. 6.5 kg ANFO = 622 % weight increase
4152 square m vs. 22,687 square m = 446 % area increase

1.25 kg dynamite vs. 6.5 kg ANFO = 420 % weight increase
4152 square m vs. 22,687 square m = 446 % area increase

1.8 kg cast booster vs. 6.5 kg ANFO = 261 % weight increase
10,964 square m vs. 29,525 square m = 170 % area increase

2.5 kg dynamite vs. 6.5 kg ANFO = 160 % weight increase
10,964 square m vs. 29,525 square m = 170 % area increase

When looking at these results it must be remembered that both cast boosters and ammonia gelatin dynamite are considerably more powerful than ANFO. This comparison is based on weights, not on the amount of energy in a particular charge. The first comparison, using different size charges of the same explosive, would be more relevant.

### *Discussion*

The ANFO charge that was primed with a cast booster produced amplitudes a little larger than the one primed with dynamite, probably because the cast primer's faster detonation velocity caused the ANFO to have a faster detonation velocity, making it a more powerful explosive.

Choosing the best size of charge to use on a particular avalanche path would depend on a number of variables. Most important might be the size of the path, wether or not you suspect deep slab instability and access to the starting zone, in regard to the worker's safety. For deep slab instabilities greater than one meter deep, it would be good to use a larger charge than the standard one kilo size, because the shockwaves attenuate considerably as they penetrate into the snowpack. A larger charge would be called for in any isothermal (wet) snowpack.

The results suggest that using fewer large charges can be more efficient than using a larger number of smaller charges.

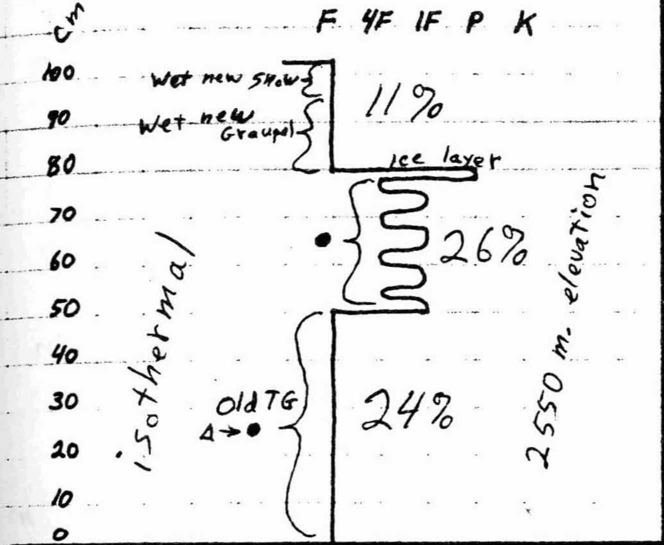
## REFERENCES

Tremper, B. (1986) How Ground Temperature Affects Temperature Gradient Metamorphism

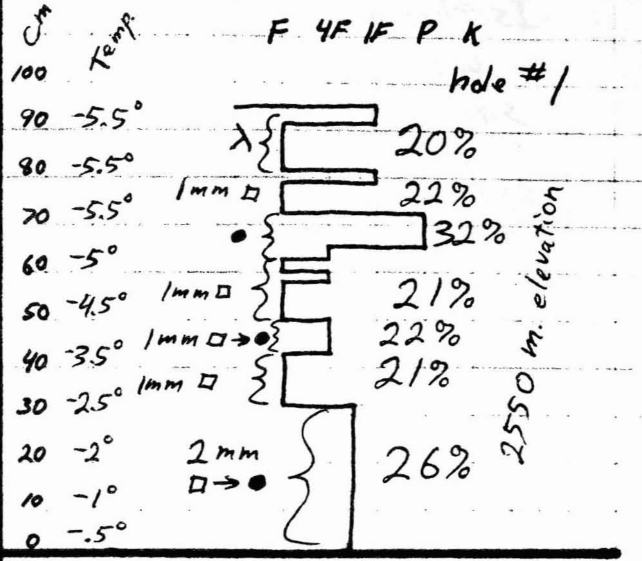
Gubler, H. (1977) Artificial Release of Avalanches by Explosives

# Snowpits From The Different Test Sites

April 1991 Isothermal



Group A 1-25-92



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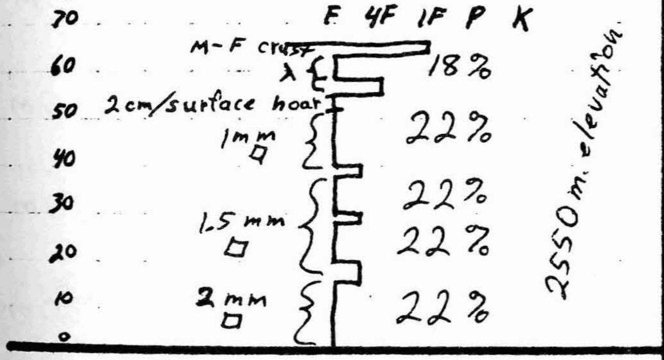

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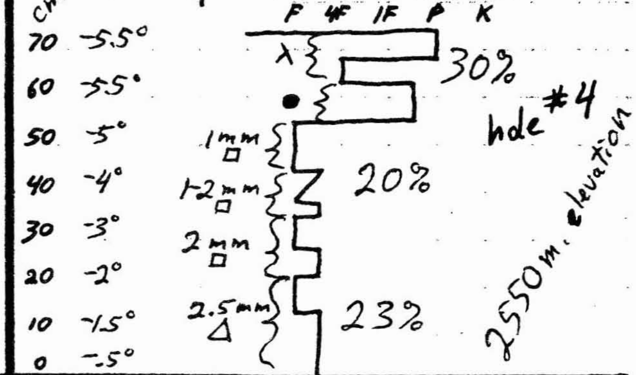
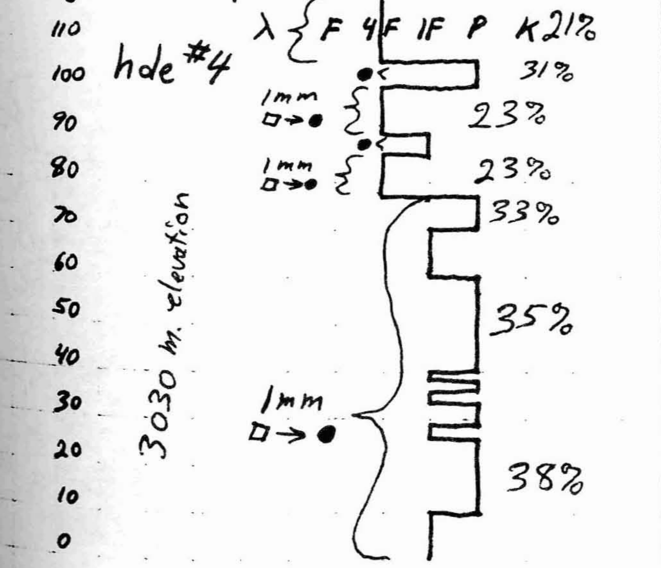


Group C 1-30-92



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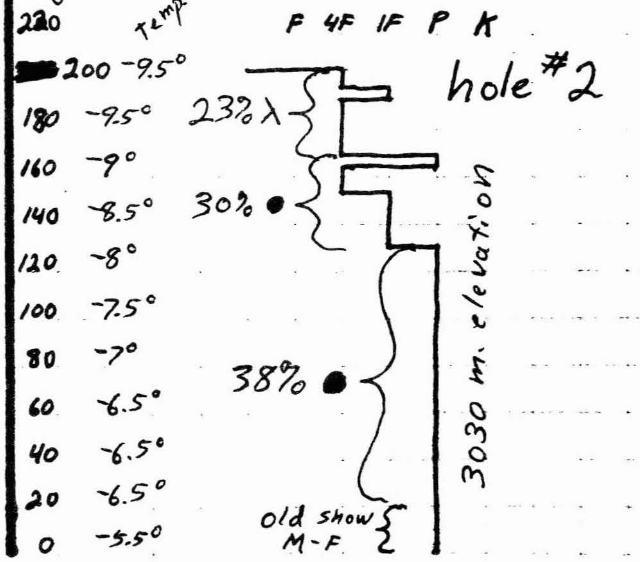
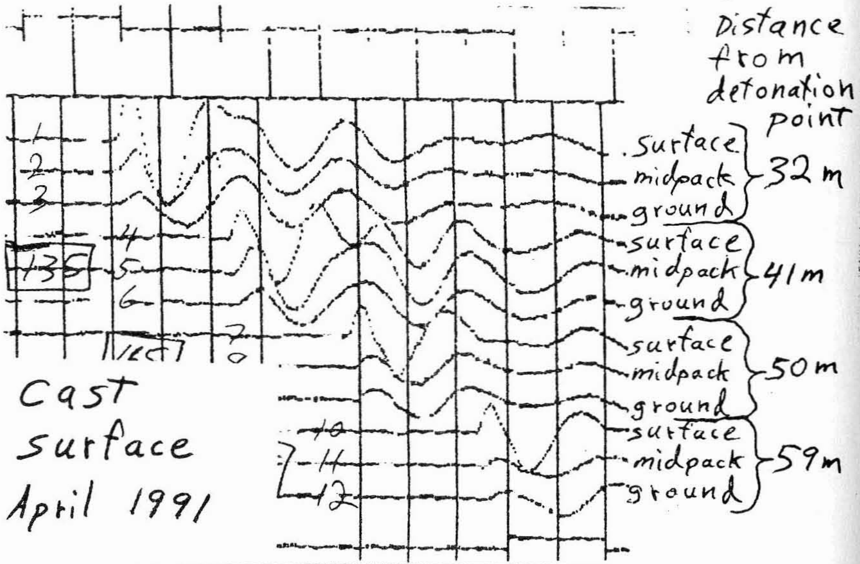


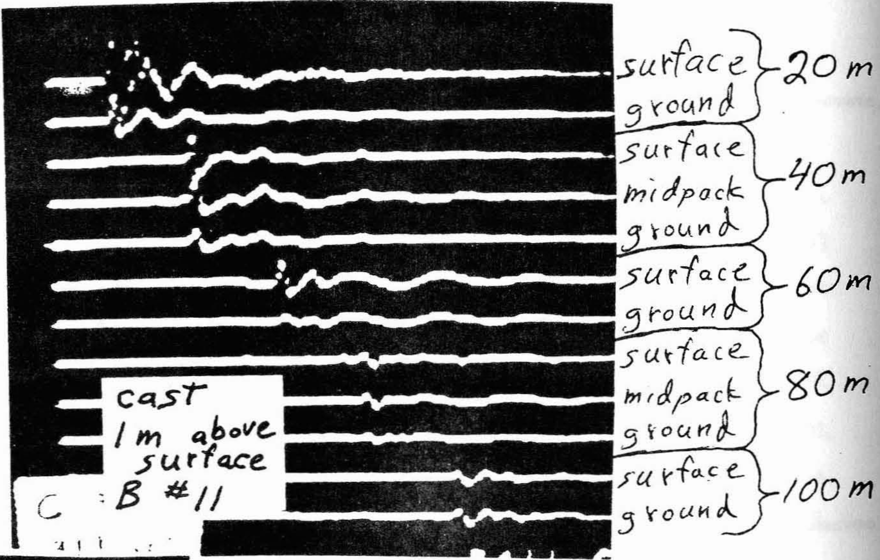
# Results From Different Snowpacks

Isothermal wet snowpack

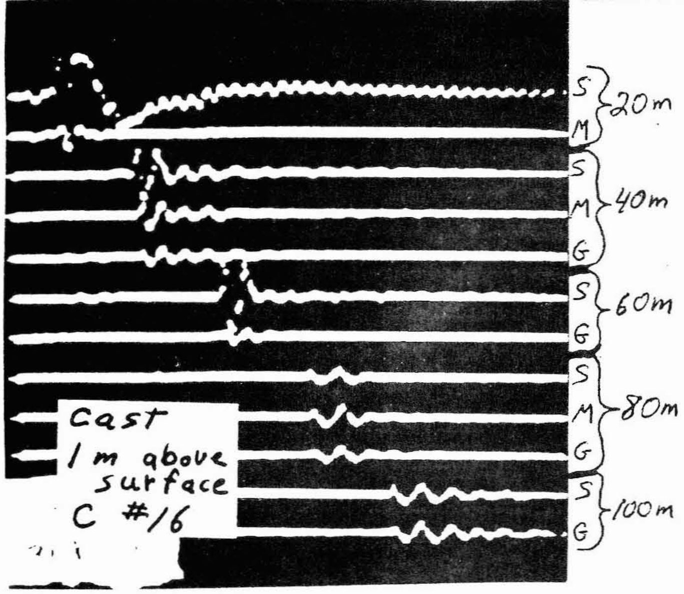


Cast surface April 1991

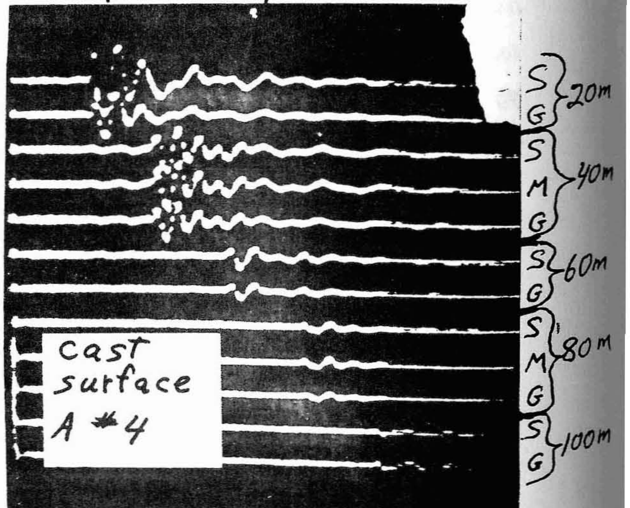
Group B Dry faceted snowpack



Group C Dry ET Snowpack



Group A Dry faceted



# Results From Different Shot Placements