COLORADO DEPARTMENT OF NATURAL RESOURCES

ROCK TALK

Division of Minerals and Geology
Colorado Geological Survey
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WHO IS THE COLORADO AVALANCHE INFORMATION CENTER?—A BRIEF HISTORY

Standing from left: Dale Atkins, Lee Metzger, Andy Gleason, Rob Hunker, Jerry Roberts, Mark Mueller, Scott Toepfer, Halsted Morris; kneeling: Stu Schaefer, Mike Zobbe, Director Knox Williams, Brad Sawtell, Nick Logan

By Knox Williams

The Colorado Avalanche Information Center (CAIC) is a program of the Colorado Geological Survey. It was founded in 1983 as a cash-funded program, meaning that it was totally funded by grants and donations. In 1995, the CAIC achieved statutory authority with the passage of HB 1314 formally designating it as a state program.

Avalanche forecasting began in Colorado (and in the U.S.) in 1973 when the U.S. Forest Service in Fort Collins began its Colorado Avalanche Warning Program. This program lasted 10 years, but then was abandoned by the Forest Service. This turned out to be an opportunity for the Colorado Department of Natural Resources (DNR), which picked up the program in 1983—provided it will be funded through grants and donations. With aggressive fund-raising (and a lot of friends), the CAIC has successfully run its program for 21 years. Currently, the CAIC derives 80 percent of its revenues from donations, grants and contracts, and 20 percent from the DNR Severance Tax Operational Fund. *(Continued on page 2)*

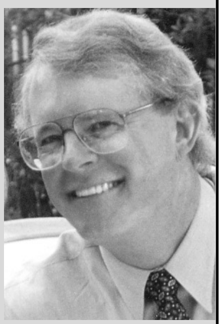
Snowology

By Andy Gleason

Why are we talking about snow in a rock newsletter, anyway? If you remember from Geology 101, ice is a mineral. It has a characteristic chemical composition, and a crystalline structure. Snow is composed of ice grains, and has a distinct stratigraphy and metamorphoses through time; so snow has rock-like properties. Snow avalanches are a geologic hazard for anyone who lives in or travels through the mountains of Colorado.

Avalanches also act as a geomorphic agent. Avalanches redistribute the snow cover which decreases spring flooding and slows summer melting. Avalanches damage vegetation which can lead to more soil erosion. Deposition rates of debris caused by avalanche erosion have been shown to be up to 4.8 mm per year. Avalanches also cause distinct landforms such as avalanche boulder tongues, cones and debris tails. While it may seem that the snow cover is simply a beautiful winter's blanket, it is more complicated and dangerous than many people realize.

From the State Geologist



Vince Matthews

As a former business executive, I am used to seeking hard data to support the success and effectiveness of programs and projects. Therefore, I am also interested in being able to document the effectiveness of CGS' programs and projects. A major part of our effort is hazard mitigation. Avalanche education and forecasting are excellent examples of successful mitigation of a significant hazard to the citizens and visitors in Colorado.

Between 1950 and 1994, at least 174 vehicles were caught in avalanches on Colorado highways resulting in 12 deaths. A number of accidents involved snowplow drivers trying to clear avalanches. In an effort to reduce these incidents, the Colorado Department of Transportation (CDOT) contracted in 1992 with the Colorado Geological Survey's Colorado Avalanche Information Center (CAIC) to forecast avalanches on the state's highways and advise on mitigation. Since then, there have been no fatalities on Colorado highways from avalanches. Also,

from the State Geologist cont. on p. 4

Our mission is simple: to reduce the impact of avalanches on recreation, industry, and transportation through a program of forecasting and education. So how are we doing? Let's look at three accomplishments that help measure our success: first, more than 3,000 people a year take avalanche safety courses taught by CAIC staff; second, avalanche deaths have not increased in the last decade—a time when Colorado's population and wintertime backcountry recreation has grown dramatically; and third, there have been very few significant avalanche incidents along Colorado's highways in the last 12 years. These are a few safety records of which we should all be proud.

A Brief Look at Colorado's Avalanche History

By Dale Atkins

Hence, the farmer watches the winter's storm with joy, while the miner, fearing snowslide and precipice, dreads its approach.

—Rev. Gibbons, 1898

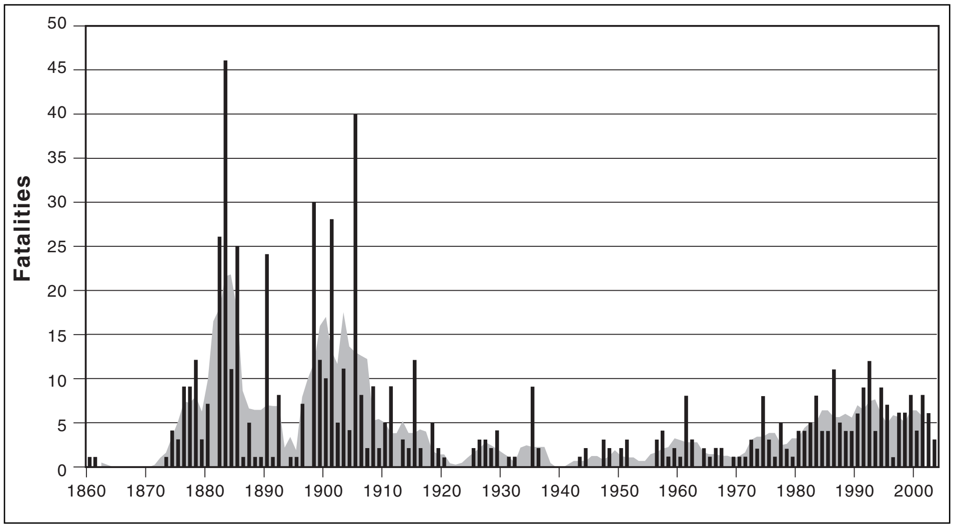
These days, winter's arrival is anticipated with joy as skiers, snowboarders, and snowmobilers ready themselves for another season of fun. But the anticipation of winter was not always exciting. A century and more ago, the thought of winter filled people's minds with fear. A miner's life was hard enough, and snow only worsened his situation.

Prior to the Gold Rush of 1859, Colorado's sparse population of Native Americans and the occasional trapper fled the mountains in winter to seek the milder climate of the lowlands. Avalanches probably killed a few unlucky mountain travelers, but the stories were never remembered. After the discovery of gold, Colorado's population exploded. Prospectors, miners, and others poured into the mountains all in search of gold and silver.

Even in 1859 miners knew the dangers of avalanches. That year Horace Tabor lost a claim to an unsavory prospector who had warned Horace and his then wife Augusta about the danger of avalanches. Alarmed, Augusta insisted on returning to Golden City for the winter. The sleazy prospector jumped their claim.

Colorado's first recorded avalanche death occurred in the spring of 1861 when two brothers were prospecting up the North Fork of the South Platte (also called Hall Valley). Another man saw the avalanche and rescued one brother, but the second was never found.

Prospectors often found ore in the steep, rocky outcrops of the high mountains—the same sort of terrain favored by avalanches. The miners lived, worked, and traveled in avalanche terrain. As the mining economy grew, so did the number of people traveling and living in the mountains. An extensive system of trails, roads, and railroads was developed to serve the mines. Camps turned into towns as more people arrived to support the miners. As a result people and property were exposed to avalanche danger. From 1861 to 1910, at least 369 people lost their lives to avalanches—miners, packers, teamsters, mail carriers, hunters, railroad passengers, and rescuers.



Colorado avalanche fatalities—1860 to 2004. Total known deaths are 643. Shaded area is 5-year moving average.

During the 1880s, mining reached its height, and this may help explain why the winter of 1883–84 was the most deadly of all. It was certainly not the snowiest, but miners were everywhere and railroads linked all portions of the state. The state's worst single avalanche accident occurred at the railroad town of Woodstock on the west side of the Sawatch Range (a few miles below the Alpine Tunnel). On March 10, a massive avalanche killed 13 people.

During the mining years, the worst accidents usually involved unsafe building locations. In February 1885, an avalanche killed 10 miners at the Homestake Mine northwest of Leadville. In February 1899, an avalanche claimed 10 miners in Silver Plume. In February 1902, an avalanche slammed into the Liberty Bell Mine burying many miners high above Telluride. Hours later rescuers were hit by a second, a third, then by a fourth avalanche. A total of 19 men died in those avalanches. A single avalanche in March 1906 killed 12 miners at the Shenandoah Mine near Silverton. By 1910 mining activity was slowing down, and World War I brought an end to many operations.

From 1910 through WWII, the population in the mountains shrank dramatically because of the steady decline in mining activity. Harsh winters continued, but fewer people in the mountains meant fewer avalanche accidents. In the 40 years from 1910 to 1949, avalanches killed only 73 people.

Prior to WWII, people went to the mountains to work, but after WWII attitudes and lifestyles changed. Soldiers returned from the war wanting to live and work in the mountains; many were members of the famed Tenth Mountain Division. Instead of mining gold, silver, or coal, they wanted to mine snow—they wanted to ski. By the 1950s, the automobile had become ubiquitous and with an improving network of year-round mountain highways, skiers poured into the high country. The ski industry was born. Avalanches posed a serious threat to skiers, and the ski areas responded by employing ski patrols and using explosives to reduce the risks. The ski industry has done a phenomenal job to create a safe ski experience. The last fatal avalanche accident to occur on a Colorado ski slope was in 1976.

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THIS ISSUE
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Winter recreationalists have also sought the solitude and challenge of the backcountry. Avalanche accidents in the backcountry have escalated. Since 1950, 201 people have died in avalanches—and that's where the Colorado Avalanche Information Center comes in.

Since the opening of the CAIC in 1983, Colorado's population has soared by more than 1.4 million people. Today backcountry skiing, snowboarding, snowmobiling, snowshoeing, mountain climbing, and ice climbing are booming sports with more enthusiasts in the backcountry than ever before. This should mean a corresponding rise in avalanche deaths. But in the 21 years of the CAIC's existence, Colorado's avalanche fatality rate—with a few ups and downs—has remained virtually unchanged at six per year, and the number of deaths per capita has fallen and continues to fall. The CAIC's program of forecasting and education works.

LIVING FOR AND LEARNING FROM THE BIG ONES

By Knox Williams, CAIC Director

Avalanches are common occurrences in Colorado. See the article entitled "Colorado Avalanche Statistics" to see just how many there are and how they affect our lives.

At the Colorado Avalanche Information Center, the everyday forecast problem goes something like this: A modest storm has laid down a fresh layer of slab snow that has bonded poorly to the snow underneath. Small to medium sized avalanches can be triggered by people going into the backcountry, and small avalanches could block mountain highways. Incidents of this sort are fairly common. It is the forecaster's job to alert the public and agencies such as CDOT to the avalanche danger expected from the small storms that are so common the Colorado mountains, and to keep serious avalanche incidents to a minimum.

But nothing sets the forecaster's heart aflutter like the Big Ones—the rare storms that produce concentrated, heavy snowfall measured by the foot, not the inch. This snow often falls on a typical Colorado snowpack that has been riddled by weak layers, so that when the avalanche fractures, it does so near the ground. These become the large, infrequent avalanches that wipe out forests, bury highways tens of feet deep for thousands of feet, hit buildings that have stood untouched for decades, run on slopes that have no history of avalanches, and, in the process, disrupt lives and make unwanted headlines. Many of these avalanches are

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from the State Geologist continued

road closure times from avalanches have been reduced, which has resulted in less economic loss to the state.

In addition to highway hazards, Colorado's beautiful mountainous backcountry attracts ever-increasing numbers of winter visitors. Avalanche conditions can vary dramatically on steep slopes, endangering hikers, skiers, snowshoers, and snowmobilers. In 2003–04, the CAIC recorded more than 2,100 avalanches. Many more certainly went unreported.

Unfortunately, Colorado recorded the highest number of deaths from avalanches in the nation between 1950 and 2002—nearly double the next highest state. However, as bad as this appears, the data show that we are making progress in mitigating the hazard through our education and forecasting efforts. With Colorado's burgeoning population, one might expect that avalanche fatalities would also be increasing, but they are not.

In the past dozen years, CAIC has educated more than 35,000 people about avalanche safety. CAIC also posts avalanche conditions for backcountry travel on its web site. In the past dozen years, we have decreased avalanche deaths per 100,000 population by 25 percent in Colorado. In the next three most dangerous states, the same measurement increased from 50 to over 200 percent. Our education and forecasting programs are paying off in lives saved.

Knox Williams, the Director of the CAIC, and I recently visited all of our forecasting offices around the state. It was a tremendous pleasure for me to learn more about the important work these forecasters do. This group of interesting, hardy, experienced, intelligent, and dedicated people work hard during the dangerous avalanche season to keep our citizens and visitors safe on Colorado's highways and in the backcountry. I am honored to be associated with them and look forward to helping them find ways to be even more effective.

what are called long-return-period (LRP) avalanches. They are rated size 5—the largest possible for their path. In short, they change the landscape and change the forecaster's perspective. Forecasters learn from the big ones.

Two or three times a decade a storm comes that qualifies as a big one. The most recent was March 17–20, 2003, and we will revisit that one shortly. But first let's visit two previous storms that hit the Colorado Rockies since the CAIC opened its doors in 1983.

February 1986

The first was February 12–24, 1986. It was perhaps the most widespread snowstorm to hit the western U.S. and Canada in the last 30 years, wreaking avalanche havoc from California to Colorado, from New Mexico to British Columbia—avalanches that caused 10 deaths.

In Colorado, it was an eye-opening avalanche cycle for the CAIC forecasters who were in only their third winter. A few notable events were:

- an avalanche in Highlands Bowl at Aspen Highlands that was 10 feet deep and dropped 3,600 feet in elevation, the largest known avalanche at this site;
- at Geneva Basin Ski Area (long since defunct), an avalanche that broke 14 feet deep;
- two large slides that blocked I-70 for the first time since the interstate had been built;
- an avalanche that roared across U.S. Highway 6 on Loveland Pass and damaged a chairlift at Arapahoe Basin Ski Area;
- avalanches that damaged buildings and mine structures at the Henderson Mine near Berthoud Pass, the Madonna Mine on Monarch Pass, and the Coal Basin Mine near Redstone;
- untold acres of mature timber demolished as avalanches widened existing paths or cut new paths.

It was a seasoning event for the team of forecasters. Avalanches rained down so numerous and large that it was the team's baptism by fire, but it brought a very positive result of a quantum leap in their experience level. A total of 750 avalanches was reported, but amazingly there was not a single death.

February 1995

Another big one came on February 8–14, 1995. This storm hit all the Colorado mountain areas—55 to 83 inches of snow in the northern mountains, 50 to 95 inches in the central mountains, and 43 to 53 inches in the southern mountains. It triggered an intense avalanche cycle with about 760 avalanches reported. Many had long return periods (LRP) as evidenced by the destruction of mature forests and buildings. Massive piles of avalanche debris ended up in areas where an avalanche had not passed in 50 or 100 years. Here are some of the extreme events that were documented:

- A backcountry skier died in an avalanche in Dry Gulch east of the Eisenhower Tunnel.
- A man was buried and killed inside his tepee home in the Conundrum Creek valley south of Aspen.
- An avalanche released in the East Vail Chutes that was six feet deep, hundreds of feet wide, fell 2,300 feet in elevation, wiped out hundreds of trees that were more than 50 years old, and buried I-70 with a debris pile that was four feet deep and 75 feet wide. This path had never hit I-70 before.
- Dozens (if not hundreds) of avalanches in the Elk Mountains that had not run in at least 30 years.
- Twelve size-5 avalanches that crossed the Maroon Creek Road between Aspen and Maroon Creek, some falling 4,000 vertical feet.
- At the Maroon Lake campground, an avalanche that had not run so large in 50 years destroyed a cinderblock bus shelter and an out-house building.
- An avalanche heavily damaged the Mace ski hut and a small forest in the Castle Creek Valley south of Aspen. The hut had been built 42 years before.
- In the Yule Creek valley, 12 size-4 and size-5 avalanches buried the Yule Marble Quarry road with debris that was measured to contain 13,570 cubic meters of snow.
- On the east side of Independence Pass, CDOT dropped one 2-pound charge from a helicopter and released the single largest slide witnessed in this entire cycle. It buried Colorado Highway 82 up to 25 feet deep for 1,000 linear feet.
- Near Gothic, north of Crested Butte, a series of 10 size-5 avalanches ran on February 14. One destroyed a forest that was over 100 years old; one demolished a log cabin that had stood since the 1890s; and one had a debris field that was measured to contain one million cubic meters of snow—the largest measurement of this kind ever taken in Colorado.
- In the Slate River valley north of Crested Butte, one avalanche had a fracture line that was 2 miles wide, and another destroyed a summer home valued at $300,000.
- West of Crested Butte, an avalanche damaged 40 parked snowmobiles ($50,000).
- Avalanches hit two condominiums at Mt. Crested Butte ($100,000).

- On Tennessee Pass, two boxcars of a Southern Pacific train were knocked 100 feet off the track.
- At Homestake Reservoir eight miles west of Tennessee Pass, an avalanche swept a 20 x 50-foot metal building off its foundation and damaged the control valves for the reservoir ($100,000). This avalanche enlarged the path width by a factor of 10, destroyed a modest forest of mature timber, and put 50 feet of debris on top of the building.
- U.S. 550 both north and south of Silverton was buried by 33 large avalanches (and uncounted small ones), which kept the highway closed for 55 hours.
- U.S. 160 over Wolf Creek Pass was closed for 47 hours because of 29 avalanches that buried the highway.

Whew! I get exhausted just reliving that storm and avalanche cycle. There were two deaths and more than $650,000 in direct property damage. Every mountain highway in Colorado was closed by avalanches or the threat of avalanches at some time during this storm. A combination of extreme instability and a high number of destructive LRP avalanches made this cycle a truly unique and memorable event in recent Colorado avalanche history.

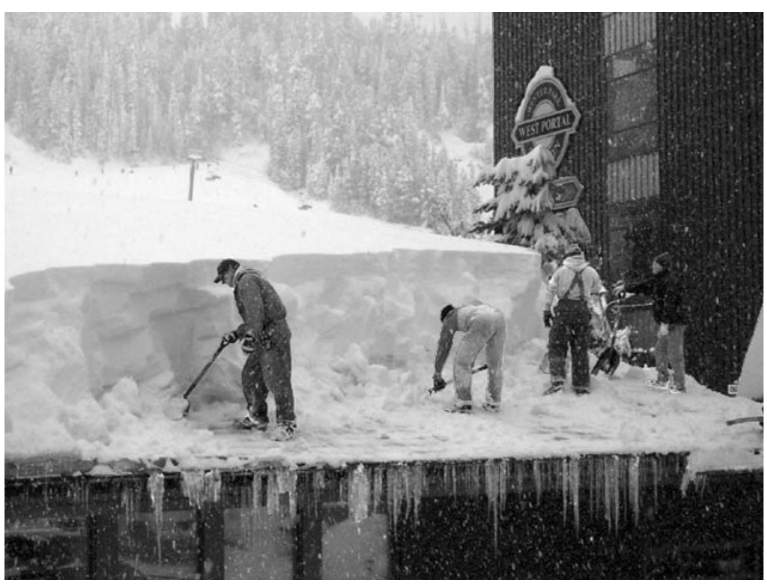
March 2003

Then there was March of 2003. This upslope storm touched the lives of everyone in the Front Range. It was the second largest snowstorm in Denver history (officially 32 inches), and snowfall in the Front Range for the 4-day storm was truly impressive: Eldora, 66 inches; Berthoud Pass, 73 inches; Winter Park, 78 inches; Bear Lake (in Rocky Mountain National Park), 80 inches; Cabin Creek near Georgetown, 83 inches; and Fritz Peak near Rollinsville, 87.5 inches.

Approximately 200 avalanches were recorded by the CAIC, but these were just the few that were obvious along highways, in and near towns and ski resorts, and in viewable backcountry sites. Some were historic avalanches in paths that had not run so big in more than 50 years (LRP avalanches). A few noteworthy events:

- The Bard Peak avalanche hit I-70 west of Silver Plume after the highway had been closed. This avalanche last ran so far in March 1948—55 earlier.
- Three small avalanches caused light damage to houses in Georgetown and Silver Plume.
- At Eldora ski resort, 250 skiers and employees were stranded for two days and nights when avalanches buried the access road.
- An out-of-bounds skier near Arapahoe Basin was buried and killed in an avalanche.
- Every highway in the Front Range was closed by avalanches or snowfall too deep to plow for extended periods.
- CDOT triggered a size-5 avalanche that ripped out a forest and put it on I-70—another avalanche that had not run so big in 50 years.
- Three days after the storm had ended, a big avalanche came off Pendleton mountain near Silver Plume and destroyed a forest, destroyed power lines, damaged Silver Plume's water treatment plant, buried the frontage road, dammed Clear Creek, and blew across I-70. See the associated article by Jill Carlson, "Silver Plume Avalanche Fallout."
- Another major avalanche destroyed the Chasm Lake shelter below Longs Peak in Rocky Mountain National Park. You can read the details in the associated article by Dale Atkins, "The Chasm Meadow Cabin Avalanche."

As with previous big events, the forecasters lived this one. Some lived it from the office—which in March 2003 felt like a command center—by tracking the storm and anticipating where and when things would start to pop. Others lived it from the highways, driving road patrols down a closed interstate and getting face shots as deeply drifted snow sprayed over the windshield. And others took to the air with helicopter



Workmen shoveling the roof of the Winter Park Lodge on Wednesday, March 19, 2003.—PHOTO COURTESY OF SKIWINTERPARK.COM control missions, taking the fight directly to the avalanches.

As with all the big ones, the storm soon ran its course. The avalanches had shown their power and destructive bent and were the undisputed masters of their domain for several days. In the aftermath, life returned to normal at the CAIC. There was data to log and reports to write. There were avalanches to study, lessons to be learned, and stories to be told.

SILVER PLUME AVALANCHE FALLOUT: NEW AND AGGRAVATED GEOLOGICAL HAZARDS

By Jill Carlson

On March 23, 2003, a large avalanche occurred about one mile west of the Town of Silver Plume. The avalanche brought trees, rock, soil and snow to the valley floor, knocked down overhead utility lines, blocked the I-70 frontage road, damaged the town's water treatment plant (WTP), and dammed Clear Creek. The dam was breached using explosives before the plant's electric pump motors were flooded. With damage to the WTP's chlorine contact tank and building, Silver Plume residents had to boil their tap water for over a month.

The avalanche occurred three days after near-record snowfall. It was triggered by additional snow loading in the starting zone caused by a change in wind direction, and began in a known avalanche path above timberline on Pendleton Mountain. Its unusually large volume and velocity caused it to unexpectedly reach the valley floor, along a path not previously identified as an avalanche chute. Rick Gaubatz, the Town's water commissioner, counted 110 rings in a spruce tree that was found in the avalanche debris at the damaged WTP, indicating that an avalanche of similar magnitude had not occurred in the immediate area in at least 110 years.

Snow and debris ran up the abutment of eastbound I-70, but did not reach I-70 traffic lanes. However, a very strong air blast would have been felt by anyone passing by on I-70. Fortunately, the avalanche occurred at about 2:30 a.m., and no one was injured. The photo above is the avalanche debris in the runout zone taken by Xcel Energy from a helicopter on the morning after the avalanche occurred.

Avalanche debris in runout zone.—PHOTO COURTESY XCEL ENERGY

The existing WTP is now known to be located in an avalanche hazard area. The Town of Silver Plume is planning to move the WTP, considered a critical facility, to a new location. The proposed site is approximately 250 feet west of the existing site, below an old tailings pile from the Johnny Bull Mine.

The Colorado Geological Survey, at the Town of Silver Plume's request, provided post-avalanche assistance and recently completed a report for the town concerning geological hazards resulting from this avalanche. We evaluated three new or newly identified geological hazards, including avalanche, debris flow (often referred to as mudslide), and rockfall, at four critical locations: the existing water treatment plant, the proposed WTP relocation site, the I-70 frontage road, and I-70. A fourth natural hazard, in-stream flooding, could occur as a consequence of future avalanches or debris flows.

Avalanche Hazard

Since a path has been cleared to the valley floor, future, smaller avalanches are more likely to reach the frontage road, the existing WTP, and I-70. Our avalanche modeling results indicate that very high velocities and impact pressures should be expected in this avalanche path. The velocities and impact pressures are probably too high for structural protection methods at the existing WTP; it is more cost-effective to relocate the plant outside of the known avalanche hazard area. For highway protection, CDOT is considering explosive control to reduce the risk of large avalanches and avalanche-related accidents along this stretch of I-70.

The proposed WTP site is better protected from avalanche damage than the existing WTP site because of a resistant rock outcrop, located about 750 feet directly uphill from the proposed site, which diverts avalanche flows to the east. The limited slope length between the outcrop and the proposed WTP site reduces the ability of an avalanche starting within this segment to attain high speeds and therefore high impact pressures.

Debris Flow Hazard

As a result of the avalanche, the slope above the existing WTP was denuded of thick stands of mature vegetation, with many trees and shrubs uprooted. The soil has been destabilized by the removal of much of its root structure. A heavy rain in the next few years, before vegetation firmly re-establishes itself, is likely to saturate the soil immediately above the soil-rock contact, and may cause the soil mass to lose strength and to slump, slide, or fail catastrophically. We have strongly recommended that personnel should avoid the area below the denuded March 23 avalanche path during and for several days after a heavy rainfall or snowmelt. The town and CDOT will need to have heavy earthmoving equipment, and a disposal site, available to clear the debris and reopen the frontage road and possibly I-70. It is possible that Clear Creek could be dammed by a debris flow as it was by the avalanche; this would add significant urgency to the Town's earthmoving effort in order to reduce the risk of water damage either to the existing or relocated WTP.

Debris flow risk is considered to be low and not to pose a significant threat to personnel and structures at the proposed WTP relocation site for several reasons. The slope above the proposed WTP site is not located within the March 23 avalanche path; therefore, it was not stripped of its vegetative cover. The existing trees, shrubs and roots serve to anchor the thin veneer of topsoil in place. As with avalanche hazard, the slope height above the site is limited to several hundred feet, so the volume of potential debris that could be mobilized is much smaller than that above the existing WTP. The slightly convex shape of the slope above the proposed WTP means that flows would not be concentrated toward the WTP.

Rockfall Hazard

The talus (boulder) fields on the slopes below Pendleton Mountain indicate that rockfall is an ongoing process in this area. As indicated by the boulders that have been raveling off of the slope since the avalanche, the rate of rockfall has increased below the path of the 2003 avalanche as a result of surface disturbance and loss of vegetation. The rockfall hazard has increased along the frontage road and at the existing WTP; however, this increase is temporary. Considering the low volume of traffic on the frontage road, the absence of a well-defined source area, and the low occurrence rate of rockfall, rockfall mitigation to protect the frontage road and existing WTP should not be considered a high priority.

Moving the WTP, at first glance, worsens the rockfall problem. A large outcrop lies from approximately 550 to 750 feet above the proposed WTP site, and represents a significant potential rockfall source area that could cause damage to the relocated WTP. We modeled the rockfall hazard at the proposed WTP site using the Colorado Rockfall Simulation Program. Our modeling results indicate that most blocks that spall off of the outcrop become trapped in the large talus field immediately below the outcrop. This is consistent with field observations. Buildings associated with the hundred-year-old Johnny Bull Mine, located immediately above the proposed WTP relocation site, do not show evidence of damage by rockfall; also we did not see any boulders on the ground in this area. The rockfall hazard at the proposed WTP site is considered to be low.

Summary

The avalanche that occurred on March 23, 2003 and damaged the Town of Silver Plume's water treatment plant produced several consequences that were not immediately apparent:

- In addition to the newly identified avalanche hazard, several geological hazards were created or exacerbated by the avalanche, including debris flow, rockfall, and flooding hazards.
- Avalanche, debris flow and rockfall hazards can be mitigated with structural protection such as deflection berms, catchments and fences; but, depending on slopes and space constraints, these can be much more expensive solutions than controlled releases, warning systems, and relocation of facilities.
- After evaluating the rockfall hazard at the proposed water

treatment plant relocation site, we feel that moving the WTP to a location outside of the March 23, 2003, avalanche path is a good example of "mitigation by avoidance."

CGS' assistance on this project has benefited the Town of Silver Plume and CDOT by providing information that will allow needed activities to be carried out safely, and provides a basis for their planning and continued use of the area. Funding was provided by the Colorado Office of Emergency Management, CDOT and CGS.

THE CHASM MEADOW CABIN AVALANCHE

By Dale Atkins

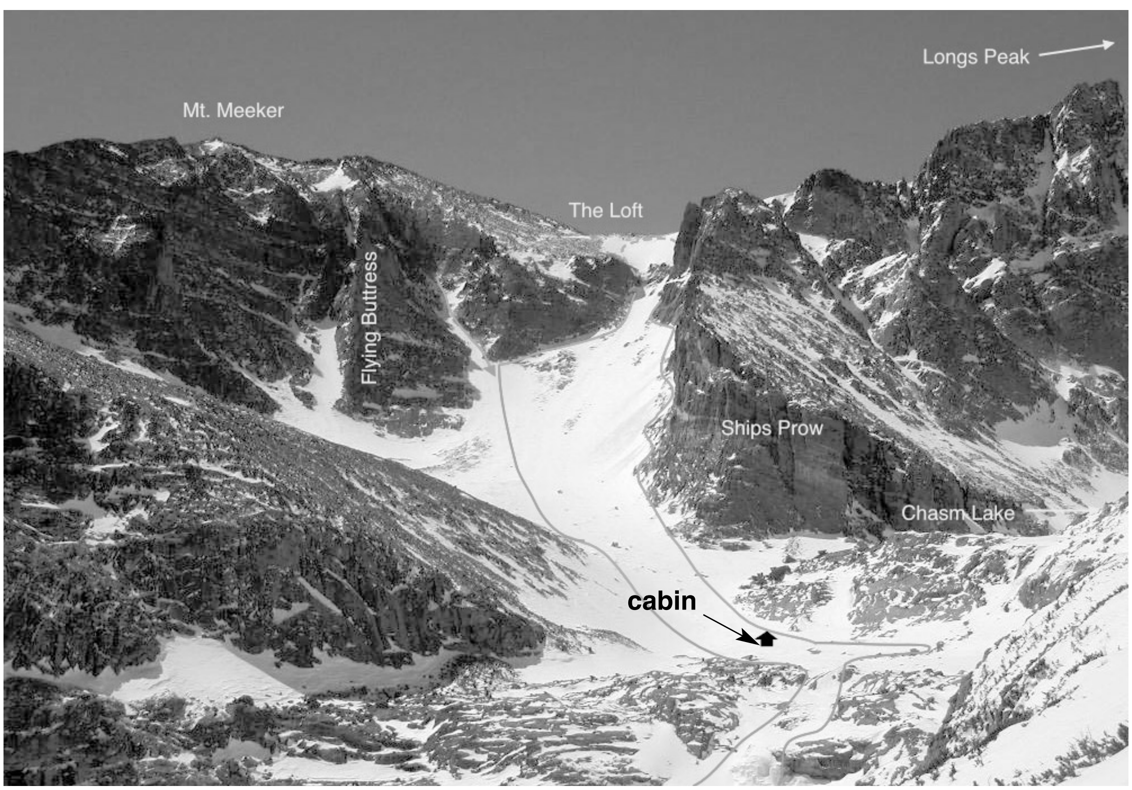
From March 17–20, 2003, a monster storm smothered the Front Range from the foothills to the Continental Divide with up to seven feet of snow. Big snows can mean big avalanches and some surprises. One of the biggest surprises was the destruction of the Chasm Meadow Cabin (Chasm Lake Shelter) in Rocky Mountain National Park.

The 12 by 14-foot stonewall cabin sat tucked at the end of an alpine meadow just below Chasm Lake. Above towered the massive east face of Longs Peak and the north face of Mount Meeker. Built in 1931 the cabin sheltered anglers, hikers, and climbers, while in more recent decades it served as a base for National Park Service Rangers. Over the years it also served as a base for countless search-and-rescue missions. The most dramatic occurred in January 1968 when it became an operating room for an injured climber. Suffering a depressed skull fracture from a fall earlier in the day, the man was stretched out onto the table. Wide-eyed rescuers held lanterns and flashlights as two physicians improvised brain surgery. The surgery was successful, and it saved the man's life. He made a complete recovery.

For more than 70 years, the cabin had stood against the elements; but on April 2, 2003, hikers stumbled upon its shattered remains emerging from the melting snow. Curiosity and a desire for photographs of the damaged shelter drove me to visit the site on April 9. At the meadow, I found the cabin gone, obliterated by an avalanche that ran sometime after the big storm.

The destruction of the cabin offered a learning opportunity. Every avalanche has a story, and it can be learned from on-site field studies, maps, and weather records. Here's what the data show happened at Chasm Meadow.

The culprit was a large and fast-moving soft-slab avalanche that released on the broad northeast-facing slope directly below the Loft—the broad, flat saddle between Longs Peak and Mount Meeker. Parts of the fracture line and flanks suggest the avalanche fractured six feet deep, or even deeper. The avalanche fell 1,600 vertical feet to the meadow. Most of the avalanche stopped in the flat meadow, but some debris spilled over Columbine Falls and fell an additional 300 vertical feet to Peacock Pool. The PCM model (Perla, and others., 1980, see CGS Bulletin 49) was used to calculate velocities and accelerations along the



Site photo with outline of the avalanche that demolished the Chasm Meadow Cabin.

avalanche path; it suggests the avalanche hit the cabin at about 88 mph. (Well upslope, the avalanche may have reached a maximum velocity of 105 mph.) The calculated peak impact pressure at the cabin was 142 kPa (3,032 lbs/ft^2). On the meadow, debris measured 200 to 250 feet across and extended 900 feet to the meadow's north edge. Chunks of the cabin's stonewalls were swept over 200 feet away. Smaller pieces of the cabin were strewn across the entire length of the meadow. From top to bottom the avalanche was nearly one mile long.

With 120 inches of snow at nearby Bear Lake, March 2003 was the snowiest month ever in Rocky Mountain National Park. This one-month total was slightly more than one-half of the average winter snowfall, and most of this snow fell in five days. From March 17–21, about 80 inches of snow with 10.23 inches of water fell at Bear Lake. Though it was a monster storm, the avalanche did not occur until several days later. Wind is a very important ingredient for Colorado avalanches; during the storm, winds were very light and from the wrong direction, blowing up the avalanche path. Wind data from Berthoud Pass and Niwot Ridge (13 miles south) suggest the avalanche most likely occurred early in the morning of March 23. (This was the same morning as the avalanche described in the article entitled "Silver Plume Avalanche Fallout.") That morning, westerly winds averaging 20–50 mph would have quickly stripped tremendous quantities of snow from the Loft and drifted the snow onto the steep slope below. In a tempest of blowing snow, the new load of drifted snow was too great and in an instant the snow fractured like a pane of glass. Thirty seconds later the cabin was gone.

Nearly every winter an avalanche or two likely releases from these same slopes; for over 70 years, all missed the cabin. Those avalanches were likely small with little volume. Very strong winds ravage the high peaks of the Front Range, causing much drifting but also stripping away tremendous amounts of snow. In general, there is not a lot of snow below the Loft. With relatively small volumes of snow, previous avalanches stopped short of the cabin or slithered harmlessly past the front door.

The difference in March 2003 was the volume of snow. A blanket of snow nearly seven feet deep covered the avalanche path from top to bottom. When the slab of snow released at the top, it entrained an enormous amount of additional snow from the track. Lower in the track, the broad slope narrows into a confined track, which accelerated the avalanche. Sitting at the edge of the meadow, the cabin was now in the sights of this bigger and faster avalanche. Its sturdy stonewalls were no match for the crushing force of moving snow.

WHAT ARE FRIENDS FOR?

By Scott Toepfer

Eight years ago the staff at the Colorado Avalanche Information Center was looking for alternative ways to get our mountain weather and avalanche forecasts to our backcountry users, and a way to bolster the shaky financial support needed to maintain these forecasts. Our telephone hotlines were getting so much use that busy signals were a problem for callers, while at the same time our revenue stream was barely adequate to provide this service. In fact, the CAIC had closed extra early in the Spring more than once because we were broke.

Our solution was to create a grassroots support group of backcountry skiers, snowboarders, snowshoers, snowmobilers, climbers and other recreationalists who would write a small check to the CAIC to keep the backcountry program alive and well. Thus, in 1997 the Friends of the Colorado Avalanche Information Center was born.

Currently, we have nearly 900 members. This is a win-win membership program: the CAIC gets the funding it needs, and the Friends get forecasts via e-mail and *The Beacon* newsletter with its unique and informative articles and occasional special bulletins or discussions of what dangers may be lurking in Colorado's backcountry.

As more people venture into the winter backcountry of Colorado, we anticipate a growing number of Friends who will anxiously await our daily updates. The staff of the CAIC strives to provide the best customer service possible. It is very rewarding to see old Friends renew their membership each Fall. We have found this program to be a wonderful aid in keeping the people of Colorado safe from the most dangerous natural hazard in the state.

Want to join? Please check out our Web site at *geosurvey.state.co.us/avalanche*, and click on the Friends of CAIC button.

Colorado Avalanche Statistics

By Dale Atkins

In the 2003–04 winter season, 2,106 avalanches were reported to the CAIC; the average is 2,293. This may seem like a lot of avalanches, but for each avalanche reported we estimate as many as another 10 go unobserved in the backcountry. Thus, in a typical winter about 23,000 avalanches occur in Colorado. Here are some other interesting tidbits.

Avalanches reported to the CAIC:

- Most avalanches in a winter: 3,081 in 1992–93
- Fewest avalanches in a winter: 1,391 in 1989–90
- Most avalanches in one month: 1,127 in February 1995

Here are some general statistics on survivability:

Survival vs. time buried (for victims in direct contact with snow):

- 15 minutes—88%, 30 minutes—50%, 60 minutes—24%, 2 hrs—16%, 3 hrs—10%
- Longest burial survival in Colorado: 17 hrs (November 1984, LaPlata Mountains)
- Longest burial survival in the U.S.: 24 hrs (December 2003, Mt. Baker, WA)
- Longest burial survival in North America: 25.5 hrs (January 1969, Canada)
- A buried victim with surface clues present has a 40% chance of survival
- A buried victim without clues, only 30%. But there is an important footnote: Prior to 1979 this survival rate was only 19%. The increase, we think, is because of beacons.

Avalanche accidents are our main concern. Here are some interesting facts concerning Colorado avalanches and avalanche victims.

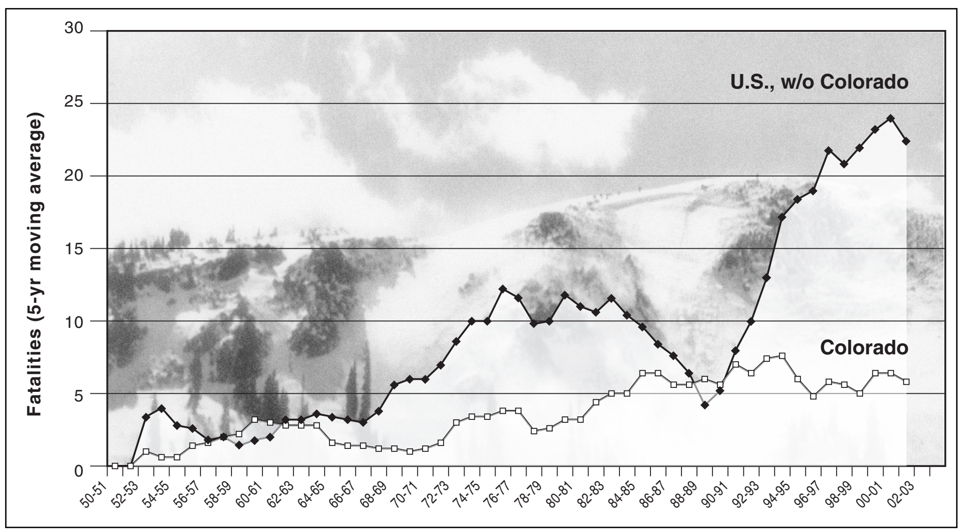
The table below shows some summary accident statistics for Colorado since 1994:

	1994–2004	*10-yr. Avg.*	*2003–04*
People caught	691	69	61
Partly buried	154	15	13
Totally buried	105	11	8
Injured	73	7	7
Killed	56	6	3

Here are some significant Colorado avalanche statistics and accidents:

- Avalanche deaths since 1861: 643
- Avalanche deaths since 1950: 201
- Most fatalities in a winter: 47 (mostly miners and residents), 1883–84
- Most fatalities in a winter since 1950: 12, 1992–93.

Education is key to saving lives. Last winter, the CAIC taught 98 courses attended by about 3,300 people. Our forecasts are received 600,000 times by people using telephone hotlines, e-mail, and our Web site. Look at the graph (below) of avalanche deaths in the U.S. and Colorado. Deaths in the U.S. are growing at a faster rate than in Colorado. Is it because of education and forecasting? We think so.



Colorado vs. U.S. avalanche fatalities, 1950–2004 (five-year moving average)

Snow Metamorphism:
The Force Behind Our Ever-Changing Snowpack

By Nick Logan

The mountain snowpack is in a constant state of change. From its creation in the Fall to its demise by Summer, avalanche forecasters study its mood swings and monitor influences that cause it to transform throughout the Winter.

You know that many rocks go through geologic changes, or metamorphose, from the influence of tremendous heat and pressure. The term metamorphism, borrowed from geology, is also used to describe changes that take place within the snowpack.

Like the earth's crust, the snowpack is comprised of different layers, each having its own unique characteristics in hardness and density. Some layers are formed by diverse snow crystals falling from the sky; some develop from drifting. Sometimes the snow melts on the surface and then re-freezes to form an ice crust that later becomes buried.

Each layer, regardless of origin, is ultimately influenced by metamorphism. But unlike rock, snow exists very close to its melting point. Thus, it takes only subtle differences in pressure and temperature to bring about change.

Soon after a snow crystal lands from the sky, it begins to change. It continues to change, or metamorphose, along with its neighbors until it finally melts in the Spring.

There are three types of snow metamorphism—*equilibrium, kinetic* and *melt-freeze*—that take place in the snowpack. *Equilibrium* metamorphism simplifies the original crystal, making it more round. Thus, we refer to the resulting snow grains as "rounds," and the process as "rounding." *Kinetic* metamorphism turns the snow grains (new or old) into angular shapes with sharp corners and flat faces, or facets like on a diamond. We typically refer to these as "squares," or "faceted grains," or simply "facets." In the Spring *melt-freeze* metamorphism builds large, round grains on the snow surface called "corn snow."

Before we examine the three types of metamorphism in more detail, here's some background information that will help you understand how these processes work in snow.

1. Snowpack properties commonly found in our continental climate zone:

- Snow depth varies greatly, even over short distances.
- Snow density varies from layer to layer—fresh powder is about $70 kg/m^3$ (7% water, 93% air); a hard layer created by drifting is about $400 kg/m^3$ (40% water, 60% air).
- Snow grains from different layers vary in size and shape.
- Air in the pore space between grains is saturated (100% relative humidity).
- Warmer pore spaces hold more water vapor than colder pore spaces.
- Snow temperature is generally warmer close to the ground, near 0°C, because porous snow is a good insulator (only 1/10,000 as efficient as copper for heat conduction).
- Snow is colder near the surface because of cold air temperatures and from long-wave radiation heat loss to the atmosphere.
- The snowpack temperature gradient is usually non-linear as it varies from the warmer ground to the colder top surface.

2. The driving force behind the type of metamorphism that will take place, equilibrium or kinetic, is the *temperature gradient* in the snowpack. A small gradient of <10°C/m (<1°C/10 cm) leads to equilibrium metamorphism (rounded grains). A large gradient of ≥ 10°C/m (≥ 1°C/10 cm) leads to kinetic metamorphism (faceted grains). Influences that control the temperature gradient include:

- Snow depth—highly variable.
- Terrain—aspect, elevation, or geothermal areas.
- Weather—warm or cold, clear or cloudy, dry or snowy

periods all affect the snow differently.

3. Another key player is *vapor pressure*. This is the pressure of confined vapor, such as found in the air spaces of the snowpack. Some important concepts to remember:

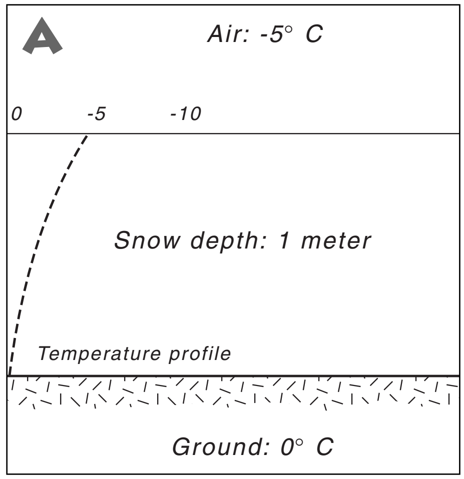
- Vapor pressure is lower over a colder ice grain than over warmer ice grain.
- If an ice grain warms, water molecules sublimate into the pore space.
- If the ice grain cools, water molecules redeposit onto the ice.
- If the pore space becomes supersaturated (>100% relative humidity), water molecules are attracted to the colder grains with a lower vapor pressure where they deposit onto the ice.
- Vapor pressure is greater over a convex ice shape (points) than over a concave ice shape (cups).
- Vapor flows more freely when the layer density is lower.

4. Snow temperature of a layer helps to determine the *rate* of metamorphism. If the snow is warm (e.g., -1°C to -5°C), the process occurs faster than if the snow is cold (e.g., -10°C to -15°C). Metamorphism comes to a virtual standstill at -40°C. But Colorado's snowpack rarely dips below -20°C, and then only near the surface.

Now let's venture out into the field, dig some holes in the snow and gather data. We'll apply the concepts above to scenarios that can be found in Colorado's snow pack.

Snowpit No. 1

This snowpit is dug on flat ground on a mild, -5°C day (see A). The measurements taken are:



A small temperature gradient promotes equilibrium metamorphism

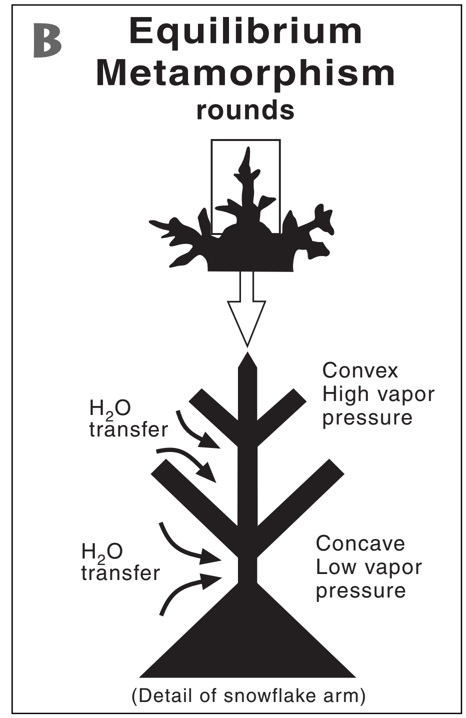
- Snow depth = 100 cm
- Snow temperature near the ground = 0°C
- Snow temperature near the surface = -5°C

What can we determine about this snowpack? The temperature gradient is 5°C/m (0.5°C/10 cm). Since the gradient is weak, *rounding* will dominate. The snow is relatively "warm" so there is sufficient water vapor for transport. There will be a transfer of mass (water molecules) from areas of high vapor pressure (convexities) to areas of low vapor pressure (concavities), through sublimation (see B and C). As this happens, necks will grow between the grains—a process called *sintering* (see D). This process strengthens the snowpack. Rounded grains with strong bonds between grains form strong snow layers.

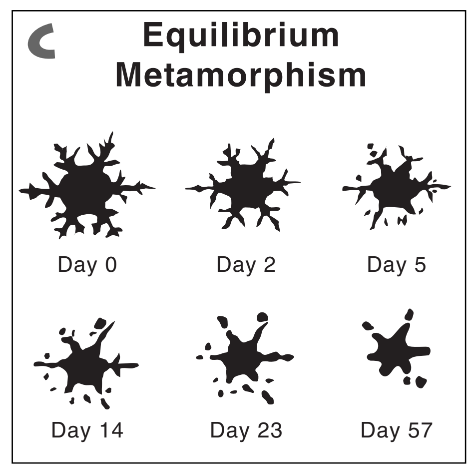
Snowpit No. 2

We've dug this snowpit several days after cold weather has set in (see E). Here are our measurements:

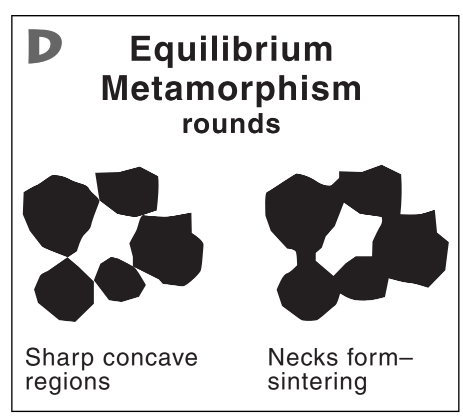
- Snow depth = 100 cm
- Snow temperature near the ground = 0°C
- Snow temperature near the surface = -10°C



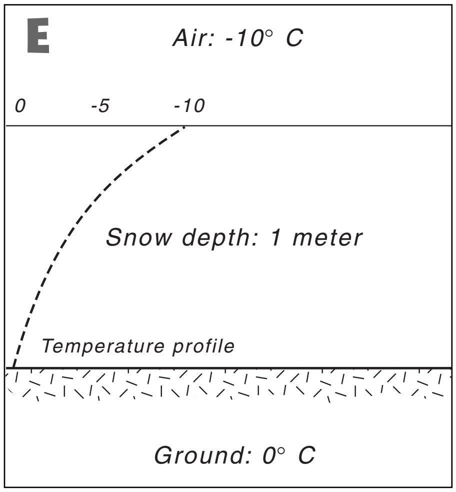
Original crystals lose their sharp points



Rounds develop from equilibrium metamorphism

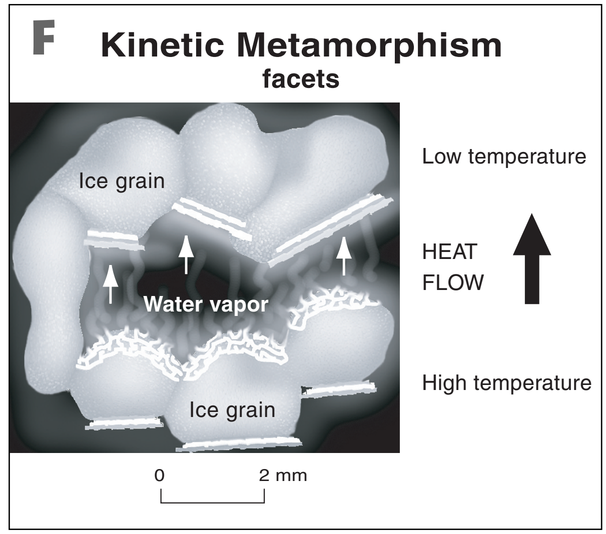


Strong bonds form between grains



A large temperature gradient promotes kinetic metamorphism

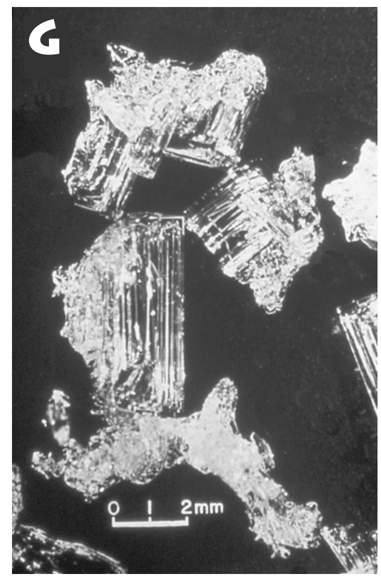
Squares developing from kinetic metamorphism



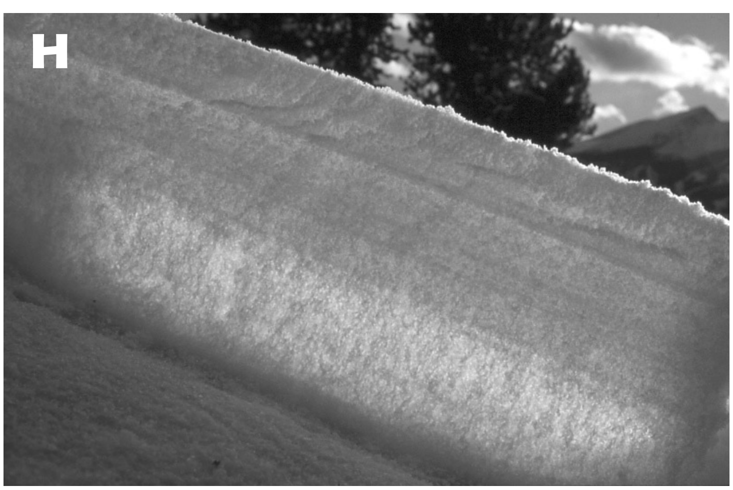
What do we know about *this* snowpack? The temperature gradient is 10°C/m (1°C/10 cm), which is twice the gradient we found in our earlier snowpit. The snowpack is still relatively warm so any metamorphism that takes place will progress at a “normal” rate. And with the strong temperature gradient, kinetic metamorphism has taken over. Therefore, we can expect squares (facets) to grow, and this will weaken that snow layer over time. And the lower the snow density, the faster the growth of facets.

In this case the water vapor doesn’t slowly migrate and deposit in the concave areas of lower vapor pressure. The strong gradient forces the molecules to leave the warmer ice grains and reattach directly onto a colder grain nearby (see diagram F, above). This occurs progressively up through the snowpack as long as a sufficient temperature gradient is sustained.

If this process were to continue for a few weeks, the resulting snow grains would look similar to those in photo G at right. These are large, angular grains called *depth hoar*, which is the result of advanced kinetic metamorphism. Note the weak bonds between the grains. This is an exceptionally weak layer (see photo H). The thin bonds between the large grains can be easily broken when stress is added, such as the weight of a person or snowmobile. This is the bane of avalanche forecasters in Colorado. This type of snow, whether in a thick or thin layer, cannot support much weight. Since these layers are subject to collapsing and causing an avalanche, they are monitored closely by avalanche forecasters.



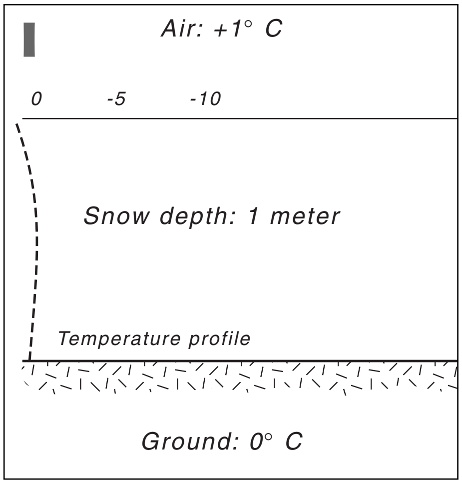
Depth hoar grains with weak bonds



A snow profile that is back lit. The lighter layer near the bottom is a weak layer of faceted grains (depth hoar).

Snowpit No. 3

Now let’s dig a snowpit on a typical day in the springtime (diagram



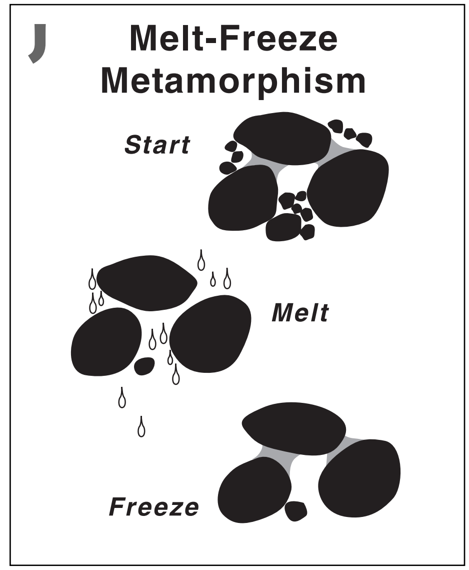
A typical spring snow temperature profile

I, above). The measurements taken are:

- Snow depth = 100 cm
- Snow temperature near the ground = 0°C
- Snow temperature mid-pack = -1°C
- Snow temperature near the surface = 0°C
- Average snow density = 300kg/m^3 (30% water, 70% air)

What do we see in this snowpack? It is now much warmer at the surface. There is only a negligible temperature gradient in the mid layers as the snow approaches isothermal conditions (near 0°C throughout). And the surface snow is starting to melt. This is the end stage of the snowpack's life. Density has increased because the snow has settled over time and the pore space has decreased. Layers that developed early or mid-winter are losing their identity because of prolonged equilibrium metamorphism. All of the grains are rounding and the snowpack is gaining strength. Thus, spring snow conditions are less risky for avalanches.

When the snow surface melts during the day and refreezes at night (regardless of the time of year), *melt-freeze* metamorphism takes over. During the melt stage the smaller grains melt first, providing free water in the snow, and the bonds are destroyed between the grains. Wet snow avalanches become likely on steep slopes, especially around rocky areas that soak up the heat on sunny aspects. When the snowpack refreezes, free water freezes onto the remaining ice grains, making them even larger than before (diagram J). This is how "corn snow" develops for good spring skiing. The snow is very strong in the frozen stage and very weak in the melt stage. Avalanche forecasts often call for different danger ratings from morning to afternoon.



The melt-freeze cycle

Summary

These simplified snowpits are good examples of how the three basic types of snow metamorphism work. But combinations of the contributory factors explored here are almost endless, making the Colorado snowpack a complex structure that develops and metamorphoses throughout the Winter. Its many layers, and the constantly-changing forces acting on them, pose a formidable challenge to the forecasters at the Colorado Avalanche Information Center.

CGS Awards Outstanding Earth Science Project Awards at the State Science and Engineering Fair

Jade Brooks, Senior Award Winner

Congratulations to **Jade Brooks** and **Daniel Neligh**, winners of the CGS/DMG Special Award for Outstanding Earth Science Project at the Colorado State Science and Engineering Fair April 8–10, 2004. The Fair was held at the Lory Student Center, Colorado State University in Fort Collins.

Jade Brooks, a 12th grader from Fort Garland, placed first in the Senior Division with her project, "Hydrophobicity II: The Effects of Forest Fires on Debris Flow," which was a continuation of her project from last year involving the Million Fire burn area by South Fork, Colorado. Jade's project involved calculating the 25-year storm event, and modeling debris flows that may originate from the watershed.

Daniel Neligh, Junior Division Award Winner

Dan Neligh, an 8th grader from Denver, placed first in the Junior Division with his project, "Erosional Investigations." His project was initiated by an artistic eye that noticed patterns in water gaps along the hogback. He then experimented with erosional processes at varying inclines to correlate uplift angle with mean spacing between gaps.

This was the first year that CGS combined forces with DMG to judge the Fair. The judging team included TC Wait (CGS), Jason Wilson (CGS), Kirsten Fisher (DMG), and Gregg Squire (DMG). CGS and DMG would like to thank all the students who presented their outstanding projects at the Science Fair.

ROCK TALK

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