ROOT CAUSES OF GROUNDFALL RELATED INCIDENTS IN U.S. MINING INDUSTRY

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ABSTRACT

The main objective of occupational health and safety research is to minimize or eliminate the events that may cause fatal or non-fatal injuries to human workers. A commonly used technique is to devise an "incident prevention plan", which is more often the product of thorough investigations of past reported incident events. Incident documentation and methodical reporting and systematic and thorough data collection, often help identify the root cause of the incident – in other words, the etiology of the incident. These retrospective analyses of the incidents can efficiently identify the future steps to take to achieve the objective of minimizing occurrence of "events of interest".

This paper introduces a novel technique – "Taxonomic Analysis", which identifies the root causes of an event (an incident in this case) and can provide future direction for corrective measures to reduce the probability of occurrence of the event. A taxonomic analysis involves systematic and organization of data based on observation, description, and classification. This paper utilizes the rock fall related incident narratives, available with the Mine Safety and Health Administration (MSHA) database (1984-1999), for a taxonomic analysis.

The study found that 67.6% of groundfall incidents occurred in supported areas with the remainder (32.4%) in unsupported areas. Some form of rock mass failure appears to cause about 50% of groundfall incidents, although in 39.7% of the overall groundfall incidents or two-thirds of those involving rock mass failure, the exact nature of the rock mass failure could not be determined from the narratives. Human activities factors such as scaling or barring down, drilling or bolting, and setting timbers or cribbing accounted for another 34.5% of the groundfall incidents. Finally, support system failures made up the remaining 15.5%. Results from this taxonomic analysis may suggest focus areas toward which preventive measures and future research activities could concentrate.

INTRODUCTION

Groundfalls are a major source of fatal and non-fatal injuries in underground mines in the U.S. Coal mines, compared to metal or non-metal mines, are more prone to groundfall-type incidents due to the nature of the rock mass involved and fundamental differences in mining practices. According to MSHA statistics during the 10-year period 1986 – 1995, groundfall was responsible for the largest proportion (31.7%) of fatal incidents in the coal mining industry and about 50% of fatal incidents in underground coal mining. Recent statistics show that the trend continues in the new millennium. Though new developments in ground control techniques helped to improve the ground stability problem in underground mines, it remains a substantial source of human fatalities (1).

This study broadly classifies groundfalls in underground mines into two categories:

a. induced or intentional, meaning rock falls are purposefully caused by the mining method such as caving rock behind a longwall face, collapsing roof in a retreat room-and-pillar mine or caving rock in a block-caving hardrock mine.
b. unplanned or unintentional, meaning any rock fall in mine workings where humans could be present.

The groundfalls of interest are the "so called" unintentional falls. Incidents due to unintentional groundfalls involve fatal or non-fatal injuries to a miner or a group of miners resulting from direct impacts of dislodged rock from the surfaces of mine openings. Groundfalls in underground mines take place in innumerable geologic and operational situations. In practice, the rock mass surrounding mine openings can collapse in different forms even though primary and secondary support systems reinforce it.

A groundfall originates from two locations that have the potential to endanger miners:

a. collapse or bursting of roof rock layers
b. spalling, slabbing or bursting of rock from the sides/ribs of openings

Occurrence of a ground-fall-related incident requires fulfillment of three conditions:

a. The groundfall itself (ground element domain).
b. Some deficiency in the support system (support element domain).

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c. The presence of a miner or a group of miners (human factor element domain).

To devise and implement a "groundfall incident prevention plan", it is very important that each groundfall related incident involving a human fatality or injuries receive a thorough investigation in order to understand the exact contributions of the three conditions mentioned above. Investigating the patterns and the root causes of groundfall related incidents, i.e., the etiology of the incident (fatal or nonfatal), is essential for improving risk management plans and establishing key focus areas for future control.

This paper introduces a novel technique – "Taxonomic Analysis", which identifies root causes of an event (an incident in this case) and in turn can provide future direction of corrective measures to reduce the probability of occurrence of the event. A taxonomic analysis involves systematic and scientific organization of data based on observation, description, and classification. This paper utilizes the rock fall related incident narratives, available from the MSHA database (1984-1999), to pinpoint focus areas in which preventive measures and future research activities could concentrate.

METHODOLOGY

MacCollum (2) addresses the need for detailed analysis of quality historical data:

> *Serious injury or death that occurs repeatedly from similar circumstances should be considered epidemic. These occurrences should be examined to identify hazards so that appropriate hazard prevention measures can be initiated in the same diligent manner that the medical profession examines a disease or infection to develop a vaccine or antibiotic for its prevention or control.*

The main objective of this study was to gain sufficient insight into the etiology of the groundfall incidents in underground mines. The first step was to access the MSHA database and develop understanding of the patterns of etiology of groundfall incidents. The MSHA database, available on the MSHA website, were reviewed for all groundfall related incidents (1984 – 1999). These data include industry-wide incident data related to fall of ground with detailed narrations of the actual incidents for coal, metal, non-metal, stone, sand and gravel mines.

Available information on groundfall incidents was organized using the principles of taxonomic analysis. Taxonomy is defined as observation, description, and classification of data into hierarchical groups according to common patterns and individual differences (3). Triggers of groundfall incidents is the basis for the taxonomic scheme, and the taxonomic scheme attempts to utilize taxons (classification parameters) in layers such that a combination of a group of taxons in successive layers paints a broad picture of the actual cause of the incident. The objective then became to create a system containing mutually exclusive categories sufficient for the classification of any eventuality.

A data set was generated for each year (from 1984-1999) of MSHA's aforementioned database. These sets contained all incidents from MSHA's accident/injury classifications (06) involving fall of face, rib, pillar, side, or highwall (from in place) and (07) involving fall of roof, back or brow (from in place). In addition, the sets included many incidents from accident/injury classification (05) involving falling, rolling or sliding rock and certain groundfall incidents from the (17) and (12) classifications involving machinery and powered haulage. The sets included the entire degree of injury range from fatality to days-lost injuries to non-days-lost injuries. Both operator and contractor injuries were included in the data sets.

After examining representative narratives of incidents within the data set, a taxonomic scheme containing five layers ranging from the broadest classifications (first level) to the most specific classifications (fifth level) was created. The first taxon layer merely identifies the incident as a rockfall incident. The second layer indicates whether the incident occurred in a supported or unsupported area. A supported area is one where the designed and approved support system was installed fully according to plan, and an unsupported area includes those areas with no support or temporary supports including an automated temporary roof support (ATRS). The third taxon layer indicates whether the mining area was active or inactive. Active areas are those where mining activities are occurring, and miners are likely present. Inactive areas include accessible but not abandoned workings where miners are not normally present such as secondary escapeways or bleeder entries. The fourth layer classifies the failure initiation as either 1) rock mass failure, 2) support system failure or 3) human activities-related failure. Finally, the fifth layer further categorizes the failure initiation mechanism or activity (trigger) occurring at the time of the groundfall.

At this time, a formal scientific basis does not yet exist for the taxonomy schema utilized, although engineering reasons exist for the proposed method. The second taxon layer recognizes the fundamental difference in risk and behavior between supported and unsupported ground. The third layer considers exposure. Active areas are where miners are expected to perform most of their normal duties, whereas, inactive areas expose very limited numbers of miners to any groundfall hazards. The fourth layer considers broad causes of groundfalls as either something geologic related (a rock mass failure), something engineering related (a support system failure) or something induced by what the person was doing (drilling, bolting, mucking, scaling, etc.). Finally, the fifth layer considers specific triggers of groundfalls.

To justify this approach, consider classification of animal species. Early classification schemes used physiological factors such as shape, bone structure and organ development to group animals into various genera and families. An underlying scientific basis for these classifications did not arise until development of evolution theory. While a firm scientific basis for ground-fall-trigger classification is desirable, an initial attempt based on experience may lead toward that end.

Each groundfall narrative in the data sets was read and classified by the taxonomic schema. Groundfalls within the sets, which did not cause injuries or did not take place in an underground operation, were not included. Narratives from 13,277 groundfall related incidents in a 16-year period (1984-99) in the U.S. underground mines were classified successfully with the schema. The actual number of groundfall incidents extracted from the accident/injury classifications was much greater though by about several thousand. Only those groundfall incidents that included sufficient information for classification by this schema (13,277 in all) were considered.

Incident reports, which included data on the volume of rock fall, were noted and classified as small (less than 0.25 ft^3), medium (between 0.25 and 1 ft^3) or large (equal to or greater than 1 ft^3). Falls from which a volume could be assumed were also included in this classification. For example, it is reasonable to assume that a groundfall that buries a victim to the waist consists of a volume of material greater than 1 ft^3. No correlation was made between the triggers of the injury causing incidents and the size of the ensuing falls.

The ages of those injured by groundfalls were also noted. The ages of the individuals were classified as under 20, 20 to 29, 30 to 39, 40 to 49, 50 to 59, and over 60. No correlation was made between the triggers of the injury causing incidents and the ages of the individuals involved.

RESULTS AND DISCUSSION

Figure 1 illustrates the year-to-year number of groundfall incidents. A downward-moving trend in the number of injuries from groundfalls exists from 1984 to 1999. Between 1991 and 1999, the number of injuries from groundfalls decreased by 42%. While this decrease seems dramatic, the number of man-hours worked in the same period also declined by 31% making the apparent decline in incident rate less impressive. The number of man-hours worked in underground coal operations, which accounted for 87% of all underground lost time injuries during the period 1991 to 1999, declined by 35% (4), indicating that the frequency of injuries from groundfalls did not decrease dramatically from 1991 to 1999.

Figures 2a and b show the five-layer taxon tree. Again, the first taxon layer merely represents the broad classification of rock fall incidents. The second layer of the classification is composed of two taxons, incidents in a supported area and incidents in an unsupported area. The third layer has two taxons, incidents in an active mining area and incidents in an inactive mining area. In layer four, there are four taxons and subsequently, in layer 5, there can be up to six taxons. A particular branch in this taxon tree maps to the root cause "inadequate number or inappropriate spacing of supports" and accounts for 11.9% of the total incidents classified. This layer five taxon belongs to the layer four taxon "incidents caused by rockfall initiated by support failure" that accounts for 15.5% of the total incidents classified. This layer in turn belongs to the layer three taxon "incidents in active mining area" that includes 67.6% of the incident database, and in turn belongs to the layer two taxon "incidents in a supported area" which also contains 67.6% of the incidents analyzed. Depending on the clarity and completeness of the narrations of the incidents recorded, these taxons can be phrased more precisely and more layers can be formed to pin point the root cause of a particular incident and the ultimate utilization of taxonomic analysis can be realized.

The taxonomic analysis of groundfall incidents in U.S. mines from 1984 to 1999 portrays a very clear picture regarding the etiology or root cause determinations of these incidents. The taxon tree shown in figures 2a and b is presented next as a "layered bar chart" in figure 3 to illustrate better the relative importance of each taxon category in terms of percent of total incidents.

Moving down the taxonomic layers shown in figure 3 provides potentially useful insights into groundfall incidents. The layer 2 taxon indicates that 67.6% of groundfall incidents occur in a supported area with the remaining 32.4% occurring in unsupported

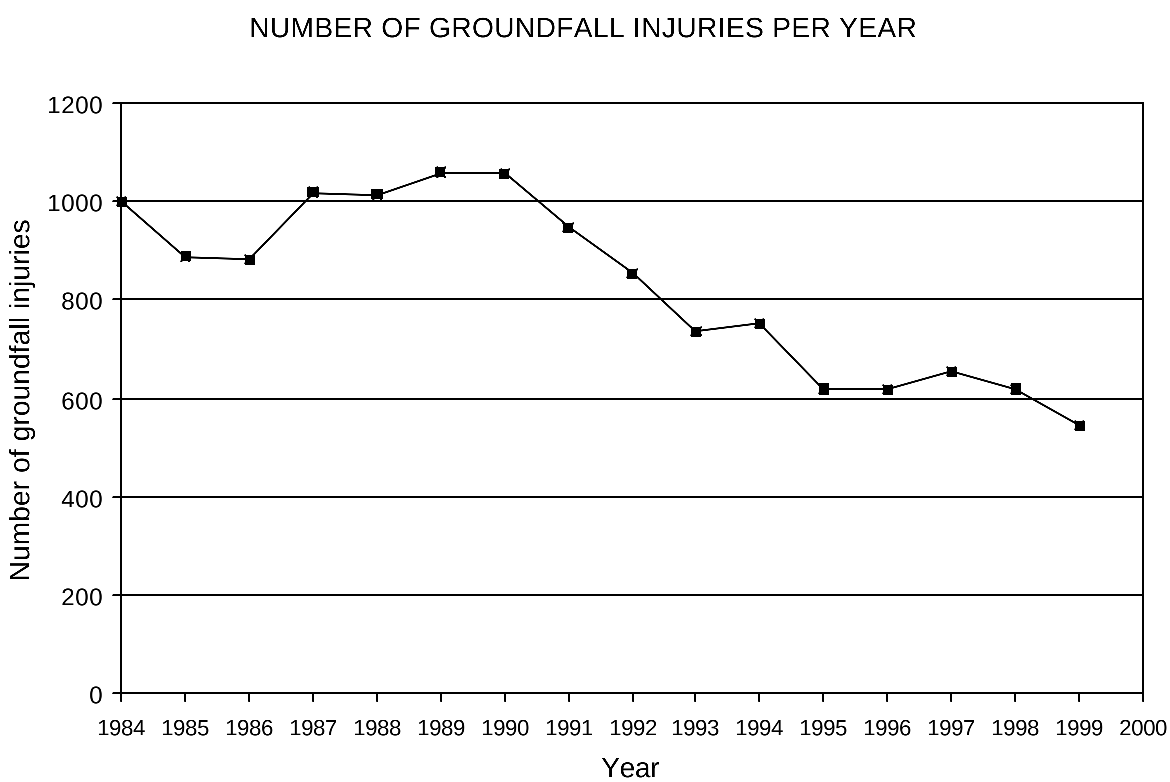

Figure 1. Annual distribution of the number of groundfall injuries (1984 to 1999).

areas. The two-thirds of all groundfall incidents that occur in a supported area suggest continuing need for improvements in support systems; however, other strategies could also prove effective such as improved hazard recognition training. The one-third of groundfall incidents that occur in unsupported areas may suggest a need for improved temporary supports or better training in support installation. The layer 3 taxon does not provide any new significant information on groundfall incidents. Fully 99.9% of all such incidents occurred in active mining areas. Evidently, very few miners are exposed to additional groundfall risks that may be present in inactive mining areas.

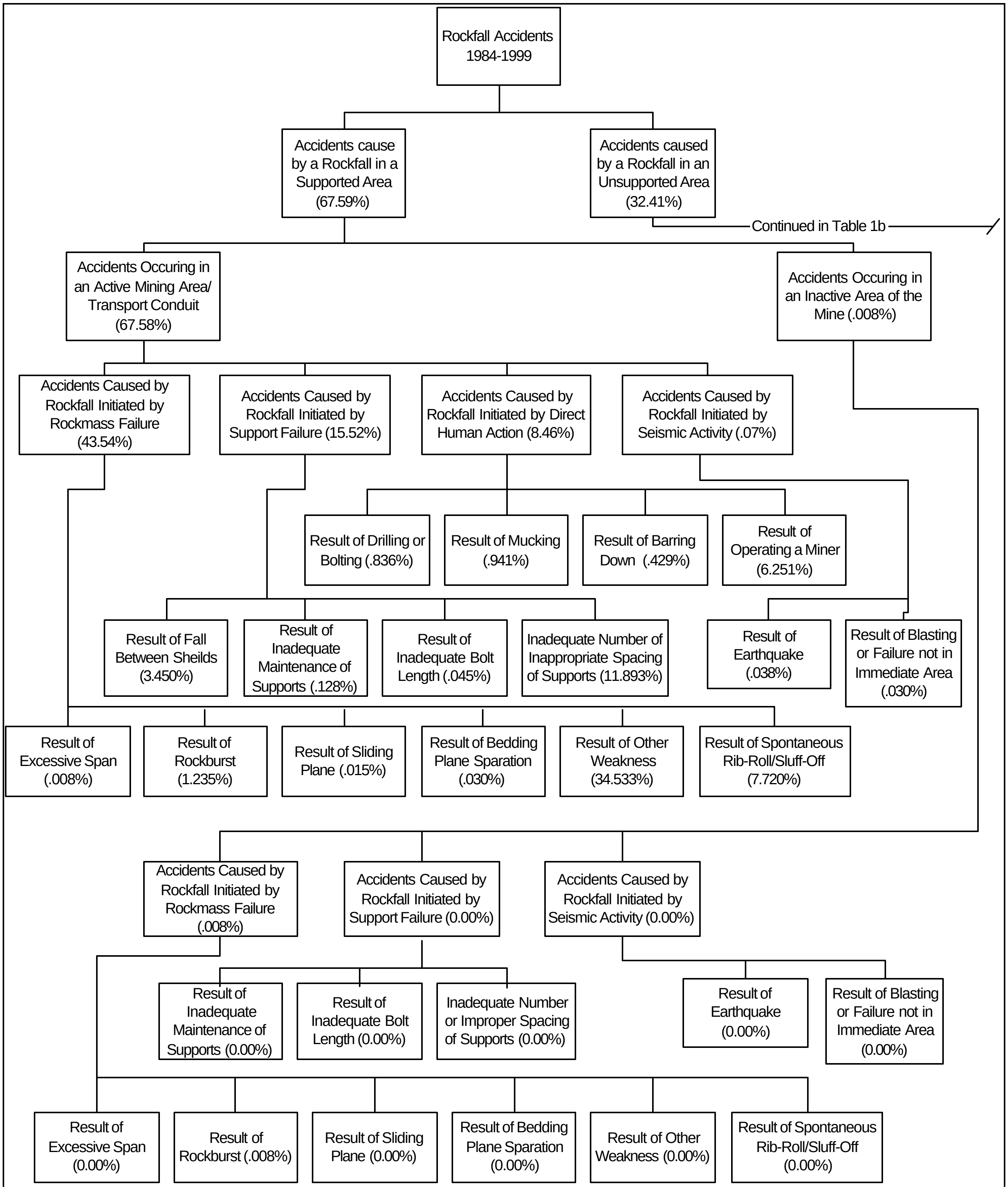

Figure 2A. Distribution of injury causing ground fall incidents by trigger (continued in Figure 2B).

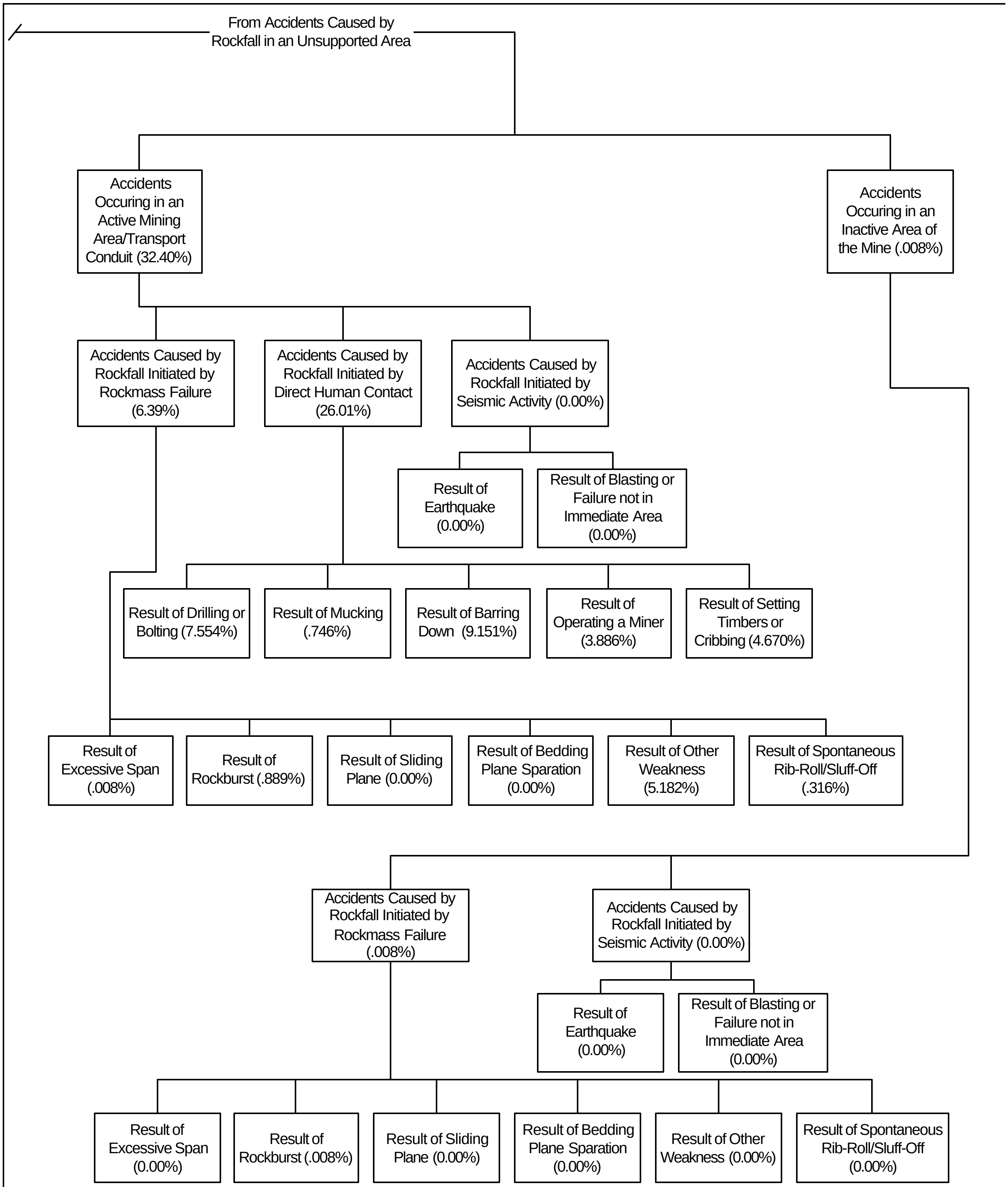

Figure 2B.- Distribution of injury causing ground fall incidents by trigger (continuation of figure 2A).

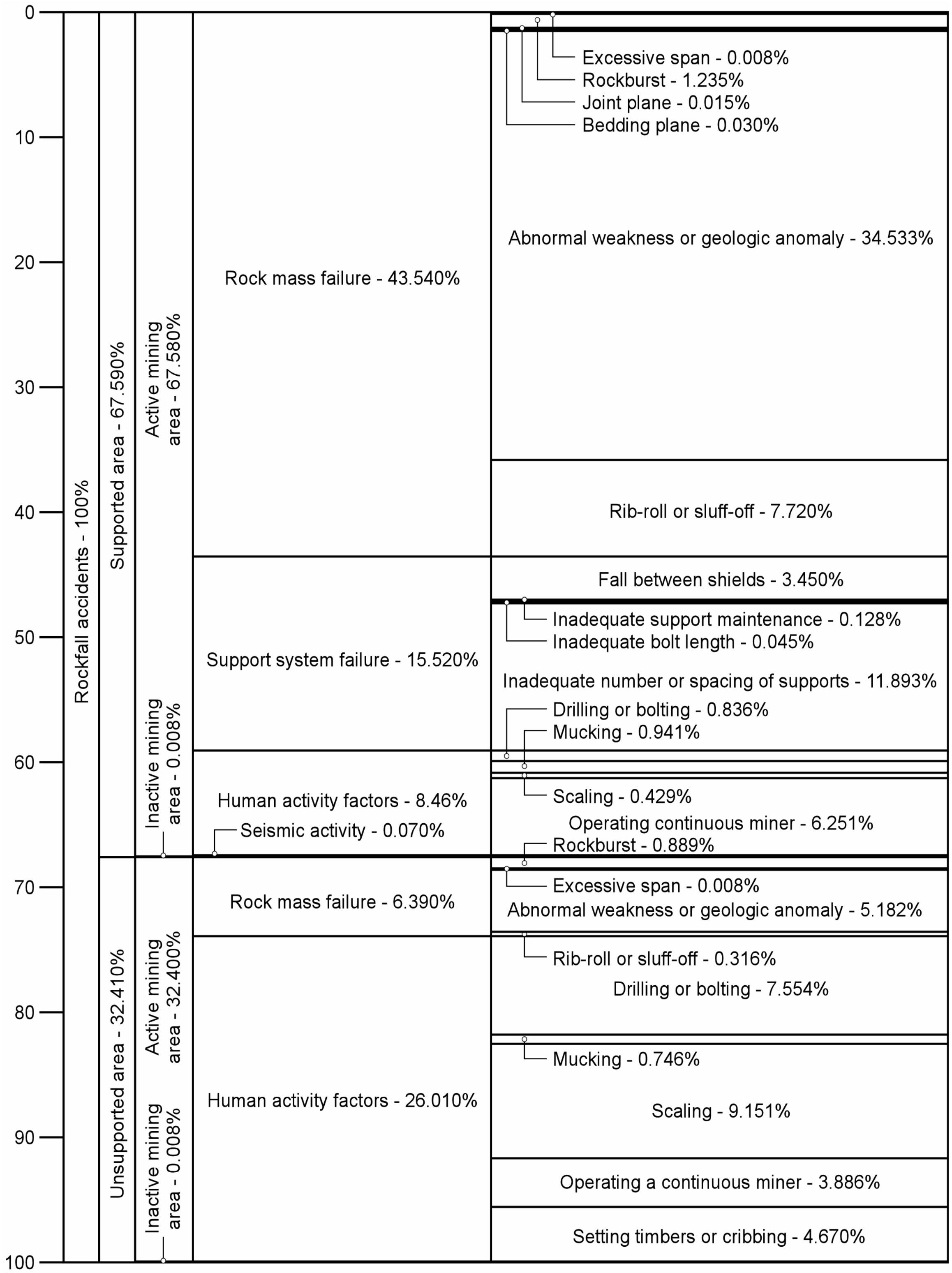

Figure 3.– Relative importance of the etiology or root cause of groundfall injuries.

The layer 4 taxon indicates that some form of rock mass failure accounted for 49.9% of groundfall incidents, some kind of support system failure caused 15.5% of the incidents and human activity factors initiated the remaining 34.5%. Thus, engineering controls to prevent groundfalls, i.e., support systems, seem to have relatively few failures. Efforts to detect anomalies in the rock mass or to improve human activities connected with support installation may be avenues for reducing groundfall incidents with more potential for impact.

Table 1 summarizes the relative importance of level-5 taxons of groundfall incidents from figure 3.

Table 1. Ranking of level 5 taxons of groundfall incidents for each level 4 taxon.

Rock Mass Failure		Support System Failure		Human Activity Factors	
Type	%	Type	%	Type	%
Other weakness	39.7	Inadequate or improper spacing	11.9	Operating a miner	10.1
Rib-roll or slough-off	8.0	Fall between shields	3.5	Scaling down	9.6
Rockburst	2.1	Inadequate maintenance	0.1	Drilling or bolting	8.4
Joint planes or bedding planes	<0.1	Inadequate bolt length	<0.1	Setting timbers or cribbing	4.7
Excessive span	<0.1			Mucking	1.7
TOTAL	**50.0**	**TOTAL**	**15.5**	**TOTAL**	**34.5**

Unfortunately, the analysis shows that the taxon "other weakness" under rock mass failure, which is defined as "falls that are not described by other categories; incidents in supported/unsupported areas which have no listed cause and from whose description no cause can be inferred", has the highest overall percentage (39.7%). In other words, the brief narratives did not provide enough information to identify clearly the root cause of almost 40% of groundfall incidents considered by this taxonomic scheme. This high percentage category may reflect inadequacies in the taxonomic scheme utilized, lack of sufficient detail in the incident narratives or some other deficiency. However, the etiology of over 60% of the 13,277 groundfall incidents considered is identified.

The most common known rock mass failure is the rib-roll or slough-off, that accounts for 8% of the incidents classified. The substantial number of incidents in this class may indicate an ongoing need for improved ribfall control practices.

Rockbursts remain an important class of rock mass failure with 2.1% of total groundfall incidents. While this percentage of rock mass failures is small, rockbursts or bumps occur in very few U.S. mines with relatively few employees. One can show that the risk of groundfall-related injury in rockburst- or bump-prone mines is much higher than the industry-wide average.

The influence of geologic discontinuities such as joint and bedding planes did not figure prominently in rock mass failure related injuries. Excessive span was also a small number. Unfortunately, "other weakness" or cause undetermined remains the biggest category under rock mass failure.

Within the class "support system failure", which account for about 15.5% of the groundfall incidents classified, inadequate or improper support spacing accounted for 11.9 % of the incidents or over two-thirds of the class. This class includes causative factors such as inadequate bolt density but may also include lack of wire mesh, mats, rib-bolting, shotcrete or other surface "skin" control.

The class "human activities factors" accounts for about 35.5% of groundfall incidents and includes those triggered by direct human/machine interaction with the rock that occurs while operating a continuous miner (10.1%), scaling or barring down (9.6%), drilling or bolting (8.4%), setting timbers or cribbing (4.7%) or mucking (1.7%). Most of these activities relate to ground support installation and may suggest the need for improved operating procedures that decrease exposure of miners to groundfall hazards.

The six top categories of root causes clearly demonstrate contributions of ground characteristics, support characteristics and human factor domains for a given incident. The rank order of these six top major root causes varies somewhat from year to year as shown in figure 4.

Figure 5 illustrates the distribution of broken rock volumes involved in an injury-incident due to groundfalls. Falls with a volume of less than .25 cubic feet were classified as small; those greater than or equal to 0.25 but not greater than 1 cubic foot were classified as medium sized, and falls greater than 1 cubic foot of total volume were classified as large. Rock fall volume could be estimated from about 1,570 incident narratives representing about 12% of the total groundfall incidents reviewed. As seems obvious, most of the injuries due to groundfalls consisted of volumes of rock greater than one cubic foot. However, small- and medium-sized rockfalls (less than 1 cubic foot) accounted for about 40% of the groundfall injuries. Missing data from the data set probably leads to an underestimate of the importance of small- and medium-sized rockfalls as an injury source.

Figure 6 displays the age distribution of incident victims; it indicates that the proportions of incident victims 40-49 and 50-59 increased between 1984 and 1999. MSHA data analyzed by the National Institute for Occupational Safety and Health (5) show that the median age of non-fatally injured miners in the US has increased between 1988 and 1997. The rising median age of miners correlates to the increase in injuries seen among the 40-49 and 50-59 age groups. The proportion of victims of groundfall related incidents age under age 20 and over age 60 remained fairly constant between 1984 and 1999, as did the proportion of the injured for whom no age was supplied, but the proportion of those injured who were 20-29 and 30-39 decreased.

There is very little doubt that the overall mining workforce is aging; for example, the average age of a coal miner was 39 in 1986, 42 in 1992 (6), and is now near 50 years. These facts, according to NIOSH, may contribute to a number of the mining injuries which occur each year; they claim that deteriorating hearing and eyesight, along with an increase in reaction time may become key mine safety issues (6). As we have seen above, however, even though the miner population has aged, the frequency of injuries (at least those associated with rockfalls) has decreased slightly, due to improvements in safety programs, geological information, ground support, and equipment. Older miners are also likely to have experience, which may help to offset many of the factors that contribute to increased injury risk.

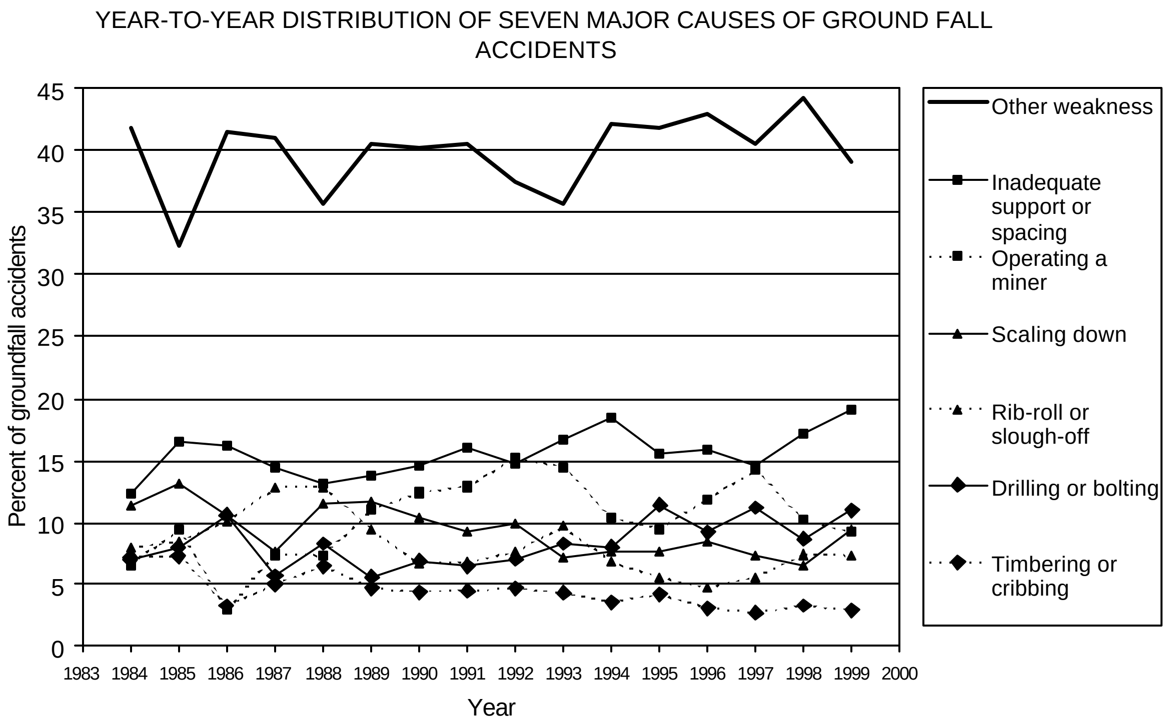

Figure 4.- Year-to-year distribution of seven major causes of ground fall incidents in the U.S. underground mines.

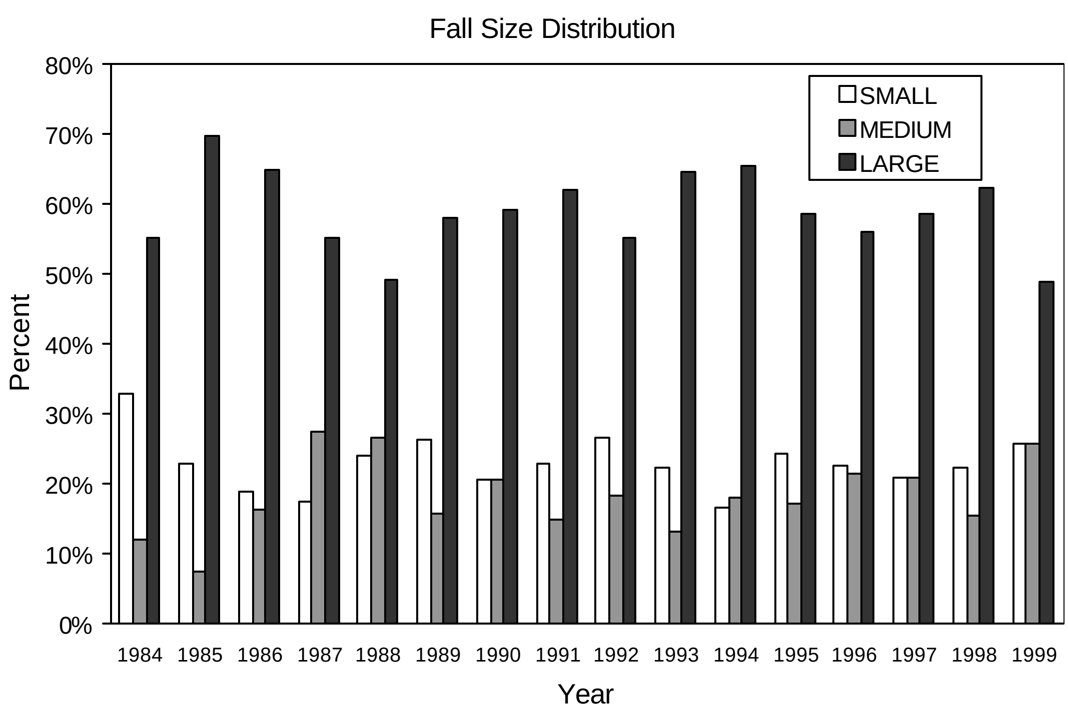

Figure 5.-Distribution of small, medium, and large falls (1984-1999).

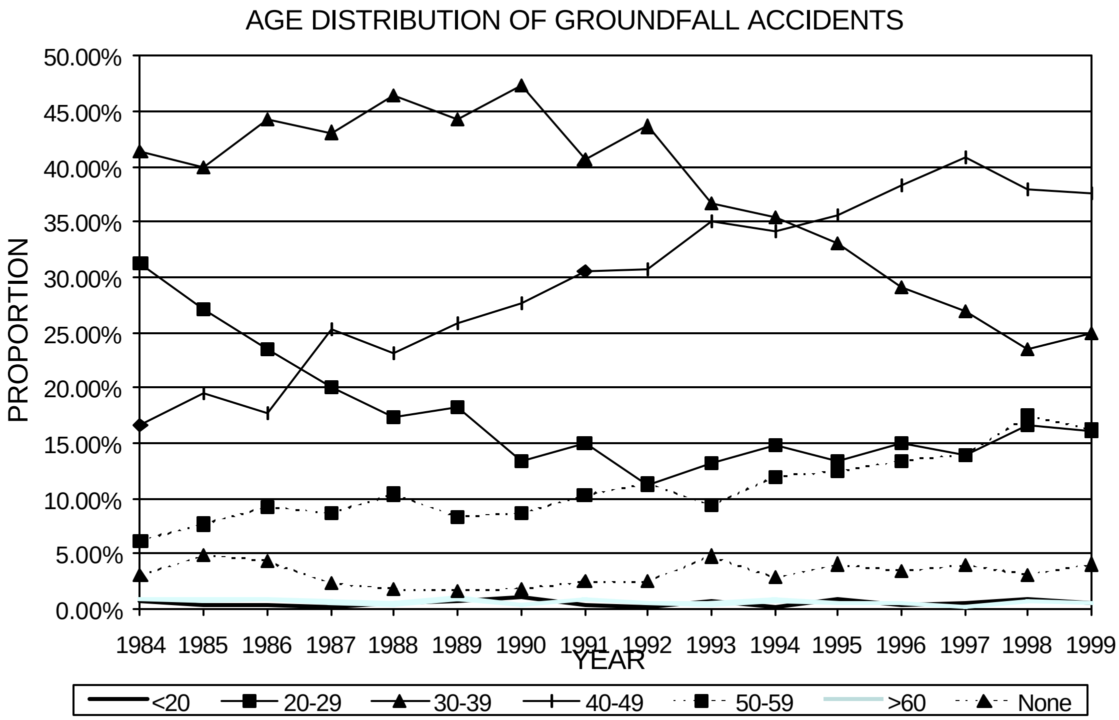

Figure 6. Distribution of ages of those injured in underground ground fall incidents (1984-1999).

CONCLUSION

Groundfalls in underground mines in the U.S. continue to be a major cause of fatal or non-fatal injuries among the miners. Over the past thirty years, improved ground control, support design and safety training for miners have managed to bring down the occurrences of groundfalls and related incidents, but the problem has remained significant.

This study identifies several areas where improvements might decrease the incidence of injury from underground groundfall incidents. Nearly 15% of injury-causing falls examined in this study can be attributed to an improperly supported roof or back; ribs rolls and slough off accounted for an additional 8%, and falls between longwall shields contributed 3%. These findings may indicate that inadequate ground support, an inadequate ground control plan or inadequate supervision of implementation is a significant problem in underground mines in the U.S. Additionally, direct human or human-machine interaction with rock triggered more than 30% of the falls. It is obviously impossible to prevent this type of interaction, but it may be possible to increase awareness of the risks involved in these types of activities (i.e., running a miner, barring down/scaling, drilling/bolting, etc.) and improving training for less experienced miners. Improved and increased training will become essential in the coming years as many experienced miners reach retirement age and those with less experienced take their place.

The database that is the basis for these results is not complete. For most injury-causing falls, the narratives provided no conclusive cause or trigger for the groundfall incident. The overwhelming majority of the falls due to rock mass failure (39.7%) were classified in the "other weakness" taxon since no information about the cause was available. Similarly, for most of the years from 1984 to 1999, 3-5% of the victims' ages were omitted from the database and in no year did more than 15.8% of the descriptions of injury-causing falls include definitive data on the volume of the fall. Reducing or eliminating groundfall related injuries will require compilation of more complete data.

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