Reports

Coal Mine Disasters: Frequency by Month

Abstract. *Major coal mine disasters (five or more fatalities per accident) in the United States over the past 150 years have tended to occur primarily in the winter months from November through April. Minor accidents (zero to four fatalities per accident) occur at a fairly uniform rate throughout the year. This peak for major disasters is ascribed to effect of barometric minima on the methane content of mine air, to the effect of dry polar air masses in reducing the moisture content of coal dust, and, possibly, to cyclic fatigue of rock structures from cycling barometric pressure. Obvious safety practices are suggested.*

A 12-year statistical study of coal mine accidents in the continental United States shows that there is a very marked tendency for major accidents and the associated fatalities to occur in the winter months, more generally November through April, as may be seen in Figs. 1 and 2.

Many of the data have been obtained from Humphrey's Bureau of Mines Bulletin 586, "Historical Summary of Coal Mine Explosions in the United States, 1810–1958," (*1*) in which there were two kinds of tabulations: (i) chronological by years for minor accidents, that is, 0 to 4 fatalities per accident for the period 1941–1956 (*1*, Tables 11 and 13); and (ii) chronological by years for major accidents involving more than 4 fatalities for the entire period (*1*, Tables 2, 3, 4, 6, 10, and 12). Neither this source nor other Bureau of Mines Publications which we have seen comment on the monthly variation in coal mine accidents.

Figure 1 shows quite clearly that minor accidents have a relatively small monthly variation. However, the major accidents arbitrarily placed in two categories: (i) greater than 9 fatalities per accident, and (ii) greater than 19 fatalities per accident, both show a very sharp increase in the winter months. This is indicated even more dramatically in the graph of fatalities shown in Fig. 2, from statistics on accidents having 20 or more fatalities each.

The dashed line in Fig. 1*c* is the average production by month of soft coal in the United States for the 4-year period 1958–1961 inclusive, from data taken from the Bureau of Mines "Mineral Yearbook" for the four respective years (Tables 8, 8, 9, and 7 respectively).

The data on which Fig. 1 is based are collected in Table 1. The ratio of accidents in January to those in June is in the range of 1 to 2 for minor accidents, but becomes as high as 6 to 7 when the fatalities per disaster are 40 or more. Figures 1 and 2 and Table 1 seem to demonstrate quite conclusively that unusual safety precautions would be in order during the period from November through April.

This situation is not confined to the continental United States but appears to be worldwide. On 9 November 1963 a major accident in which there were over 170 fatalities occurred in Japan. I was able to obtain through the Tokyo office of Dow Chemical Company a meteorological report from the Fukuoka area. This reported a barometric low in the Sea of Japan on 8 November, with hard storms at sea. Newspaper clippings from abroad might be cited: Saar, Germany, February 1962, 270 dead; Germany, 9 March 1962, 28 dead; England, 22 March 1962, 16 dead; Springhill, Nova Scotia, 24 October 1956, 78 dead (this, incidentally, was a rock fall and not an explosion). The two worst mine disasters in history were at the Honkeiko Colliery in Manchuria, 28 April 1942, 1549 fatalities; and at Courrieres, France, 10 March 1906, with 1060 fatalities. The worst disaster in the U.S. occurred 6 December 1907 at Monongah, West Virginia, with 361 fatalities.

The data in Figure 1 and Table 1 can be interpreted as follows. Minor accidents with 4 or fewer fatalities per accident appear to be a concomitant of coal mining activity and occur with essentially constant frequency throughout the year. Presumably, both a source of ignition and ignitable material (methane or coal dust, or both) are present the year around. During the winter months some additional factor must enter to convert an otherwise minor accident into a major accident.

We were led to make this inquiry by a specific incident and a resulting hypothesis. On 21 December 1951 there was a severe coal mine disaster in West Frankfort, Illinois (119 fatalities). At that time a recording barometer in Midland, Michigan, showed a precipitous drop, while newspaper accounts of the disaster commented that severe winter weather was hampering rescue operations. Charles Darwin (*2*), in commenting on earthquakes and weather in South America, said: "There appears much probability in the view first proposed by Mr. P. Scrope that when the barometer is low, and when rain might naturally be expected to fall, the diminished pressure of the atmosphere over a wide extent of the country might well determine the precise day on which the earth, already stretched to the utmost by the subterranean forces, should yield, crack, and consequently trem-

Table 1. Coal mine disasters by month and by severity over a period of 148 years.

Month	Fatalities per accident					
	0–4	5–9	10–19	20–39	40–79	> 79
January	33	32	19	8	7	6
February	24	35	17	12	2	2
March	28	45	21	8	6	5
April	23	30	18	4	3	6
May	35	31	13	4	4	4
June	37	16	6	0	1	1
July	23	27	9	5	1	1
August	25	24	14	4	0	1
September	21	14	7	2	0	0
October	32	24	19	6	1	1
November	41	32	23	6	3	3
December	40	28	15	10	4	4

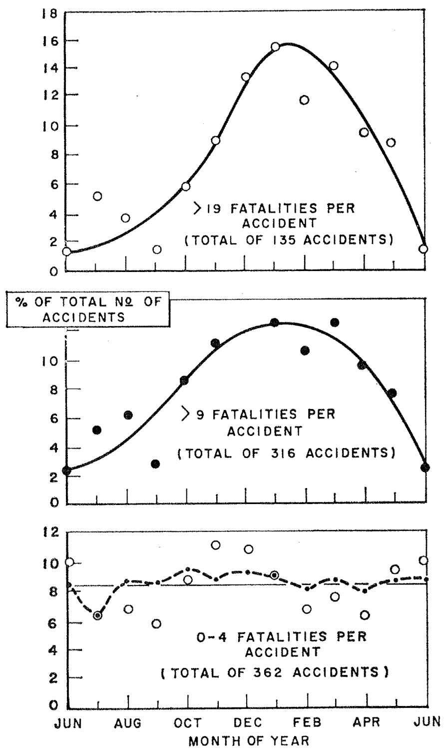

Fig. 1. Ordinate is percentage of all coal mine accidents of the indicated severity occurring in the indicated month. The circles in the bottom curve are for minor accidents with less than 5 fatalities per accident for the period 1941–1946. The dots and the dashed line in the bottom curve represent the percentage of annual bituminous coal production in the United States per month, averaged for the 4-year period 1958–1961 inclusive.

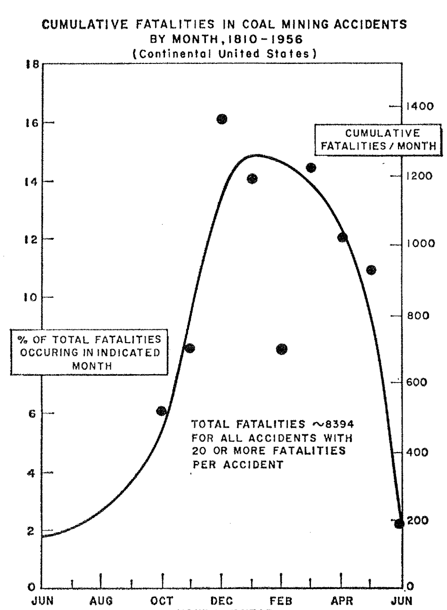

Fig. 2. Occurrence of coal mine fatalities by month for major coal mine accidents during the period 1810–1956 for the continental United States.

ble." Since changes in barometric pressure are both more abrupt and more intense in the winter months, I speculated that the attendant change in load on the earth (10^6 metric tons per 2.6 square km (1 square mile) per 25 mm pressure change) could release copious quantities of methane or initiate failure of coal or rock seams or both. This, in turn, led to my study of mine disasters by month.

Merritt (*3*) has cited reference material indicating that other workers have also discovered correlations of coal mine accidents and barometric pressure. Hosler (*4*) states: "Sharp pressure falls due to cyclogenesis in the region, passages of deep pressure troughs, deepening of stationary low pressure systems, or the passage of rapidly moving cold fronts with associated squall lines create conditions in gaseous coal mines that are favorable for explosions."

McIntosh (*5*) discovered two aspects of the weather which could affect mine disasters, namely (i) at the time of a low barometric pressure, methane content reaches a maximum, frequently rising above the lower explosive limit; (ii) the cold polar air mass which may follow a low barometric pressure removes moisture from coal dust and makes it more ignitable. Before I was aware of the studies by Hosler and McIntosh, I obtained from the U.S. Weather Record Center in Asheville, North Carolina, a number of barometric tracings obtained in some city near the mine disaster for a period of 1 to 4 weeks preceding the disaster. In many instances there was no unusual barometric activity. However, at West Frankfort, Illinois (21 December 1951); Centralia, Illinois (25 March 1947); and Springhill, Nova Scotia (24 October 1956), there had been marked cycling of the barometric pressure for at least a month before the disaster. For example, in the 50-day period from 1 November to 21 December 1951, the barometer at Springfield, Illinois, fell from an average high of 750 mm to an average low of 735 mm 12 times, according to an irregular sine wave pattern. This suggested that fatigue resulting from cyclic stressing of underground rock and coal structures might be important. This is a complex question for which there are insufficient data to give a definitive answer. The Springhill, Nova Scotia, disaster (*6*) was a rockfall with no explosion, and presumably there was no question of low relative humidity. Judging from the reported "bumps" which occurred for several months prior to the actual disaster, Springhill could represent a pure case of fatigue from cyclic variation of the barometer and then actual failure with the specific barometric low which preceded the disaster.

Meanwhile, Calvin (*7*) has called attention to a calculation given recently (*8*) concerning differential pressure loads on the earth's crust during hurricanes. The barometer may fall for a moment by 50 mm, equivalent to 2 million metric tons per square mile over the land while ocean waters may rise as much as 3 meters, equivalent to 10 million metric tons per square mile, a differential pressure of 12 million metric tons per square mile. It may be of interest to note that an intense Atlantic Ocean storm was in progress (*9*) at the time of the worst coal mine disaster in the United States (6 December 1907). Barometric records from two nearby locations—Elkins and Parkersburg, West Virginia—showed no abnormal behavior before the severe disaster at Monongah. This suggests, on very slender evidence, that events some distance away from a given mine disaster could cause shifts in the load on rock strata, which loads are transmitted to the given mine. The 9 November 1963 Japanese disaster involved a mine in the port city of Omuda at a time when there was a storm at sea.

In conclusion, the period from November through April is one in which severe coal mine disasters are most likely to happen. This is ascribed to either of two causes: the well-documented studies by Hosler and McIntosh on increase in methane content and decrease in coal dust moisture associated with barometric changes; and the hint in this report of purely mechanical failures initiated by cyclic fatigue, earth loads, and so forth. Corrective action could take one of several forms, namely (i) generally enhanced safety precautions in winter months, (ii) use of hygroscopic materials on coal dust, (iii) use by mine superintendents of the criteria developed by McIntosh (*10*) for forecasting explosion conditions in coal mines, and (iv) shift of as much mining activity as possible to the summer months.

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References and Notes

1. H. B. Humphrey. Published by U.S. Government Printing Office, 1960
2. Charles R. Darwin, *The Voyage of the Beagle, Vol. 29* of The Harvard Classics, (Collier, New York, 1937), p. 356.
3. Paul C. Merritt, Managing Editor of Mining Engineering, Personal Communication on 11, September 1963.
4. C. L. Hosler, *Trans. Am. Geophys. Union* **29**, 607 (1948).
5. C. B. McIntosh, *Geograph. Rev.* **47**, 155 (1957).
6. *Report of the Royal Commission Appointed to Inquire* into the Upheaval—at Springhill, Nova Scotia—on the 23rd Day of October, A.D., 1958 (Queen's Printer, Halifax).
7. Professor M. Calvin, Univ. of California at Berkeley, private communications.
8. Western Edition, The New York Times, 15, October 1963.
9. New York Times, 8, December 1907.
10. C. B. McIntosh, *Trans. Illinois State Acad. Science* **50**, 133 (1957).

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Geometry of Bermuda Calcareous Dune Cross-Bedding

Abstract. *Bermuda wind-blown limesands are lobate-shaped bodies composed internally of leeward foreset strata which dip at 30 to 35 degrees and windward strata which dip at 10 to 15 degrees in an opposite direction. The foreset beds are convex upward. This convex upward cross-stratification is preserved because of the early stabilization of the eolian calcareous sand due to surface cementation by percolating rain water.*

The geometry of cross-stratified sedimentation units has received considerable attention during the past 10 years (*1*). It is now accepted, perhaps unintentionally, that for all practical purposes, the geometry of cross-stratified calcareous and siliceous rock units is the same. The geometry of the Bermuda wind-blown limesands suggests that early stabilization of calcareous skeletal particles produces distinctive cross-stratification.

The stratigraphy of the Bermuda land rocks has been discussed by various writers (*2*). About 95 percent of the exposed land of Bermuda is composed of calcareous dune formations of presumed Pleistocene age. The individual dunes appear to be predominantly lobate sand bodies which have coalesced to form irregularly defined transverse dune ridges. Figure 1 shows various aspects of bedding within the lobate sand bodies. In Fig. 2 an idealized lobate unit is illustrated.

Internally, the lobate unit is composed of leeward foreset strata which dip at 30 to 35 deg and windward strata which dip at 10 to 15 deg in an opposite direction when undisturbed. The configuration of the base of the unit depends on the topography over which the sand body was deposited.

The foreset cross-beds are slightly convex upward and usually abut sharply against underlying surfaces, but may continue leeward into the windward strata of another unit. Some cross-beds are tangent to the base. The cross-stratification surfaces are convex downwind. The foreset beds pass windward into strata which dip 10 to 15 degrees in an opposite direction or are truncated by younger beds. Repeated truncation of the cross-bedding in a leeward direction by successively younger beds with slightly divergent dips is common.

The leeward cross-strata may be as thin as 2 mm or as thick as several centimeters. They are commonly ripple-marked or broken by root casts. The individual cross-beds range from 0.5 to 25 meters in length. Thickness of the cross-stratified lobate units varies from 0.3 to about 20 meters. The sand bodies are up to 100 meters in the longest dimension. Brecciation of the bedding occurs within or between the units.

The windward strata are commonly very irregular and complexly bedded. Blowouts filled with sediment are found in the windward beds. Irregularities in the windward strata have thus far prevented better definition. The convex upward cross-strata and the curved cross-bedding, which is convex downwind, suggest that the lobate unit is a true parabolic or U-shaped dune form.

The leeward cross-beds which are convex upward apparently represent periods of aggradation of the lobate

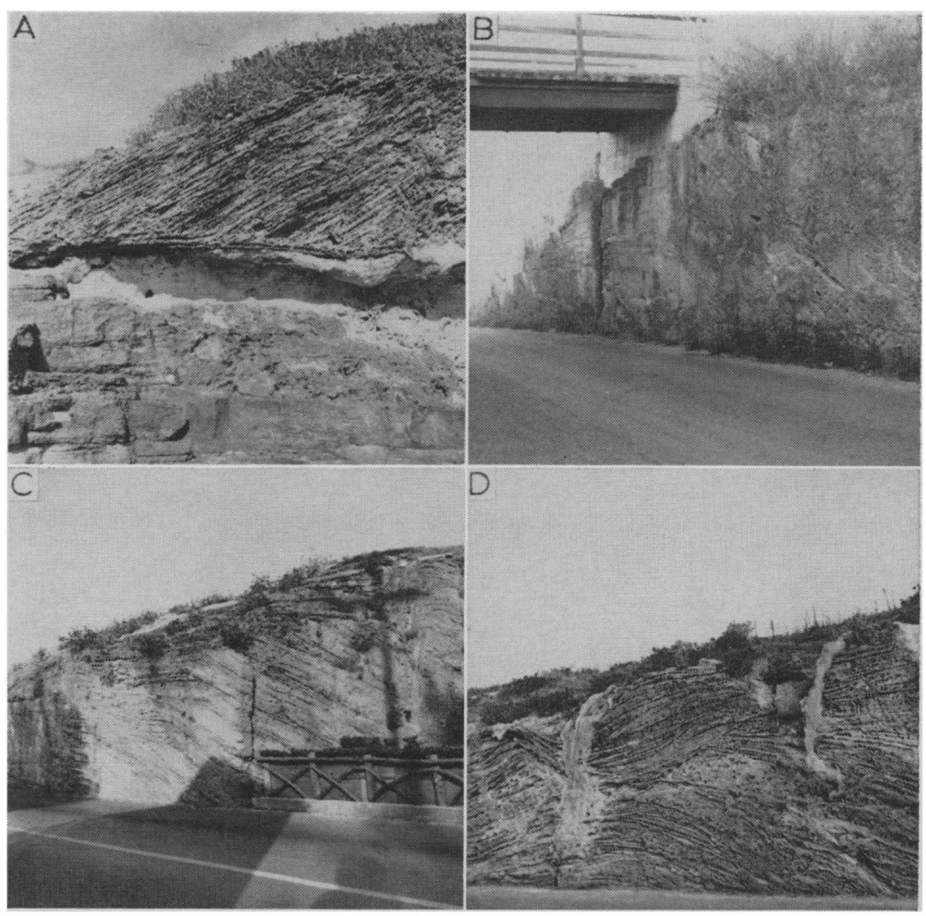

Fig. 1. Aspects of bedding within lobate sand bodies. *A*, Cross-bedding, convex upward portion of cross-bedding is eroded (see Fig. 2, *1*). *B*, Roll-over of windward strata into convex upward leeward cross-beds (see Fig. 2, *2*). *C*, Truncation of older strata by younger in a leeward direction (see Fig. 2, *3*). *D*, Irregular bedding in windward beds of eolian sand body (see Fig. 2, *4*).