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Dynamic failure in coal seams: Implications of coal composition for bump susceptibility

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A B S T R A C T

As a contributing factor in the dynamic failure (bumping) of coal pillars, a bump-prone coal seam has been described as one that is "uncleated or poorly cleated, strong…that sustains high stresses." Despite extensive research regarding engineering controls to help reduce the risk for coal bumps, there is a paucity of research related to the properties of coal itself and how those properties might contribute to the mechanics of failures. Geographic distribution of reportable dynamic failure events reveals a highly localized clustering of incidents despite widespread mining activities. This suggests that unique, contributing geologic characteristics exist within these regions that are less prevalent elsewhere. To investigate a new approach for identifying coal characteristics that might lead to bumping, a principal component analysis (PCA) was performed on 306 coal records from the Pennsylvania State Coal Sample database to determine which characteristics were most closely linked with a positive history of reportable bumping. Selected material properties from the data records for coal samples were chosen as variables for the PCA and included petrographic, elemental, and molecular properties. Results of the PCA suggest a clear correlation between low organic sulfur content and the occurrence of dynamic failure, and a secondary correlation between volatile matter and dynamic failure phenomena. The ratio of volatile matter to sulfur in the samples shows strong correlation with bump-prone regions, with a minimum threshold value of approximately 20, while correlations determined for other petrographic and elemental variables were more ambiguous. Results suggest that the composition of the coal itself is directly linked to how likely a coal is to have experienced a reportable dynamic failure event. These compositional controls are distinct from other previously established engineering and geologic criteria and represent a missing piece to the bump prediction puzzle.

1. Introduction

Dynamic failure events in an underground coal mine, or "bumps", are defined as "the sudden, violent bursts of coal from a pillar or pillars or a block of coal, resulting in a section, the whole pillars, or the solid block of coal being thrown into an open entry" [1]. Reports of disastrous and often fatal dynamic failure events date back over one hundred years in the United States. Mining practices and technologies have significantly evolved over the course of the last century, yet these events continue to occur. The events at Crandall Canyon, Utah and Brody No.1 Mine in West Virginia are two recent failure events that resulted in a total of eleven fatalities. These events testify to the fact that dynamic failure remains an imperative safety concern [2,3]. Furthermore, their continued occurrences indicate that engineering controls have proven inadequate at wholly mitigating the problem.

Multiple conditions have been associated with the occurrence of dynamic failure phenomena, including:

(1) Thick and competent strata that can create a bridging effect, resulting in high abutment stresses [4–10].
(2) Overburden thicknesses greater than 150–210 [1,7].
(3) A strong coal that is resistant to crushing or that is "uncleated or poorly cleated, strong…sustains high stress and tends to fail suddenly" [4,8,7].
(4) Presence of sandstone channels or rolls that can serve to concentrate stresses [4,6].
(5) Fracturing of strong units above or below the coal seam [10].
(6) Slip along pre-existing discontinuities [10,11].
(7) Multiple seam mining interactions [1,6,12,13].
(8) Mining sequences that can cause anomalously high stress concentrations [6,12].

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This list represents a compilation of factors that have historically been associated with the occurrence of dynamic failure phenomena. Peng states that, "a bump may occur even though one or more…[generally accepted] geological conditions are not present [1]." Rice suggested that a combination of factors, rather than one or two specific circumstances, is required to facilitate a bumping event [7]. Identifying a set of conditions that will consistently produce bumping, however, has proven elusive; conditions generally associated with dynamic failure might produce an event at one site but not another. Conversely and more troubling, dynamic failure could occur where relatively few of these factors exist, although some are usually present.

In conventional coal pillar design, coal is often treated as an approximately homogenous material with a uniaxial compressive strength of 6205 kPa [14]. While this practice is generally accepted, coal deposits are, in reality, heterogeneous. While treating coal as a substance that exhibits consistent material properties provides effective tools for mine design, these tools have proven ineffective at completely eradicating dynamic failure events [15,16]. In fact, it could be that the differences between coal deposits hold the key to answer the question of why some coals appear to fail violently more frequently than others.

Dynamic failure events have a propensity to occur regionally or locally as indicated by the geographic clustering of bump incidences, shown in Fig. 1. This supposition is supported by anecdotal evidence: Peperakis describes notable cases from the Sunnyside Mine in Utah where failure events occurred during the development in virgin ground, "in localities a long way from active pillar workings"—conditions not normally associated with dynamic failure phenomena [17]. He states that these events could have been facilitated by the presence of faulting. However, faults certainly exist in other regions, yet bumps during the development phase of mining are extremely rare. This observation corroborates those of Babcock and Bickel who proposed that some coals, notably those from western coalfields, could be inherently more prone to exhibit bursting-type behavior in a laboratory environment [18]. This suggests that some coals could be more inherently susceptible to bumping than others, creating a greater risk when coupled with the factors which are already known to contribute to bumping phenomena.

Previous efforts to understand and model coal bumping have focused on the mechanical properties of coal (among other factors). Some of these have included unconfined compressive strength (UCS) and stiffness as primary variables [1,7,12,19]. Agapito and Goodrich indicate that cleat density could also contribute to dynamic failure in Western coal mines [4]. While these researchers have approached the problem from different angles, it seems that the ultimate goal of these observations is to describe the capability of a coal to retain energy prior to failure and thereby resist crushing. This energy could be subsequently released kinetically, in the form of a dynamic failure event. Thus far, however, these observations have failed to yield a consistent set of physical parameters that produce bumping. Furthermore, the tests required to attain these values could be time-consuming, difficult, or costly. Therefore, it would be prudent to examine other, more accessible coal attributes for correlation with bump susceptibility.

Significant success has been achieved in correlating the material properties of coals with their elemental and petrographic characteristics. Laubach et al. defined an empirical relationship between vitrinite reflectance and cleat density [17]. Van Krevelen, Van Krevelen and Schuyer describe empirical relationships between the chemical composition of coal and acoustic properties, Hardgrove grind ability index (HGI), thermal and electric conductivity, porosity, calorific value, and other attributes [20,21]. Mathews et al. provide an overview of empirically determined relationships between both elemental and petrographic parameters of coal composition and many of these physical properties [22]. Given that coal composition directly influences the optical, physical, and material properties of coal, we hypothesize that elemental and/or molecular variables are fundamentally linked to dynamic failure events. This concept is not without precedent; Brauner makes the observation that bumps were not observed in coals with less than 12% volatile matter [23]. This correlation between bumping and coal composition is echoed by Osterwald, Dunrud, and Collins who stated that there was an apparent correlation between bumping and the presence of benzene in the coal matrix [24]. This leads to the deduction that it could be possible to use coal composition to predict bump susceptibility. Were it possible to define the applicable components of coal, it would provide a more accessible and potentially more reliable measure of bump susceptibility than the commonly accepted mechanical property tests.

The Pennsylvania State University Coal Sample Bank and Database maintains an archive of bulk coal samples and a database of detailed characterizations of coal samples acquired from active or previously active mines across the continental United States.

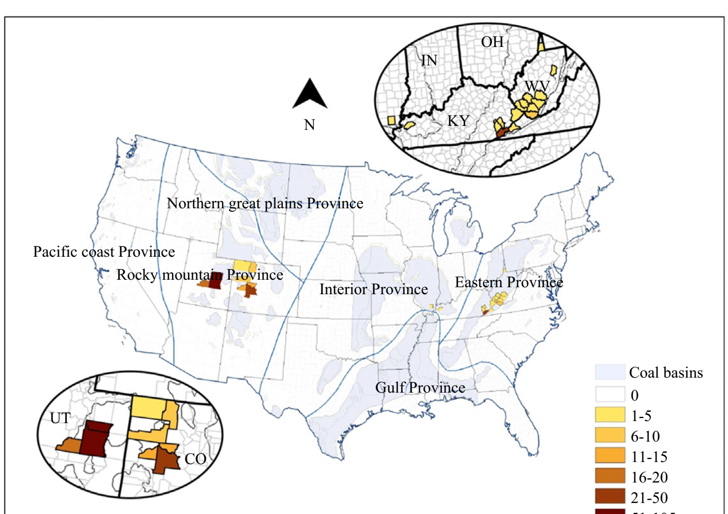

Fig. 1. Regional clustering of reported bump phenomena by country, compared to coal basins.