

Proximity detection of explosive methane clouds in longwall mines

J.F. Brune, H.S. Düzgün, G.E. Bogin Jr., A. Juganda, C. Strebinger,
T. Nguyen, E. Isleyen & C. Demirkanr
Colorado School of Mines, Golden CO, USA

ABSTRACT: Methane detection in underground coal and other gassy mines traditionally done with point-type sensors or by certified examiners using handheld meters. To provide a sufficient margin of safety, machine-mounted point sensors shut down equipment at methane concentrations of 1 or 1.5%, yet many mine fires and explosions have shown that point sensors may not be capable of detecting explosive methane clouds. The 2010 explosion at the Upper Big Branch mine in West Virginia, USA, is one such example that killed 29 miners. Researchers are using multi-point methane readings, CFD, and 3-D modeling to produce the real-time methane distribution cloud and visualization through virtual and augmented reality (VR and AR). Knowing the position of the shearer, shields and other ignition sources creates a proximity detection model for the methane cloud that will automatically shut off the shearer or other equipment before an explosion can happen.

1 INTRODUCTION

The 2010 methane and coal dust explosion at the Upper Big Branch Mine in West Virginia, United States, killed 29 miners. Investigators (Page, 2011) found that worn cutter bits on the drums of the longwall shearer likely ignited a cloud of flammable methane-air mixture that had migrated into the face area from the gob fringe behind the shields. As Brune and Sapko (2012) demonstrated, it is easily possible that flammable or explosive mixtures form near the cutter bits that remain undetected by the methane sensors mounted on the shearer body, the headgate and tailgate drives. This calls into question the validity of point-type methane readings that have long been used worldwide to protect miners from methane explosions, as this was likely a contributing cause of the Upper Big Branch explosion.

Figure 1 is a depiction of methane emanating from a fissure in the coalbed from Kissell (2006). It shows that the ventilation flow quickly dilutes methane through the explosive range, yet the Kissell's figure does not provide a scale or airflow quantity—it is merely a sketch.

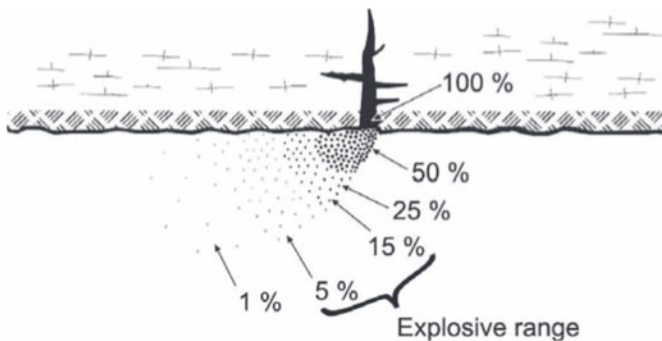


Figure 1. Dilution of methane emanating from a fissure in the coalbed (Kissell, 2006).

The U.S. Mine Safety and Health Administration (MSHA) issued guidance (MSHA, 2013) for certified mine examiners to test for methane with handheld detectors “within 5 feet of the face and at least 12 inches from the roof, face, ribs, and floor.” Reasons for these distances are not specified but one can assume that the 12-inch (0.3m) standoff relates to the dilution depicted in Figure 1 while the 5-foot (1.5 m) standoff from the face is designed to keep the examiner from traveling beyond the last row of roof support.

In the United States the limit for methane detected is 1.0%. At this level, all “electrically powered equipment in the face shall be de-energized and other mechanized equipment shall be shut off” (30 CFR §75.323). This applies regardless whether the methane is detected using a handheld or machine-mounted sensor. MSHA may permit up to 1.5% CH₄ in the longwall face, provided that certain enhanced methane monitoring provisions are met. In this case, the shearer will alarm and must be de-energized at this level and corrections made to reduce CH₄ below 1.5%. Automatic power shutdown must occur at 2% CH₄ (see U.S. regulation 30 CFR §75.323 and §27.24). In most cases, machine-mounted sensors are directly linked to de-energize the equipment automatically. If 1.5% or more methane is detected in a working place, all persons must be removed from the affected area except those required to restore ventilation. U.S. law also permits up to 1.5% or even up to 2.0% in specific return air courses.

These methane limits are common to many countries. Most countries require mine-wide atmospheric monitoring systems, but such systems are not currently mandated in U.S. coal mines. In any case, all methane and atmospheric monitoring systems rely on point-type detectors placed at strategic locations to test both the fresh air and the exhaust airways.

2 METHANE DISTRIBUTION IN THE LONGWALL FACE

Researchers at the Colorado School of Mines (CSM), with funding from CDC NIOSH, have conducted extensive work with computational fluid dynamics (CFD) studying airflow distribution, leakages between the face and the gob, and methane distribution patterns. From a CFD modeling perspective, a longwall face ventilation is quite complex. Shearer and face conveyor are moving obstructions, and the shield support, hydraulic hoses, cables etc. are difficult to model in sufficient detail. Therefore, in another project funded by NIOSH, CSM researchers are constructing a 1:40 scaled longwall model for physical airflow and explosion testing.

Figure 2 shows the plan view of the CFD longwall model with airflow velocity contours shaded in color according to the legend provided. These contours are valid for approximately 1.5 m above the mine floor. This is a bleeder ventilation system typical for a U.S. coal mine, with layout, geometry and airflow quantities adopted from an actual mine. In the model, the

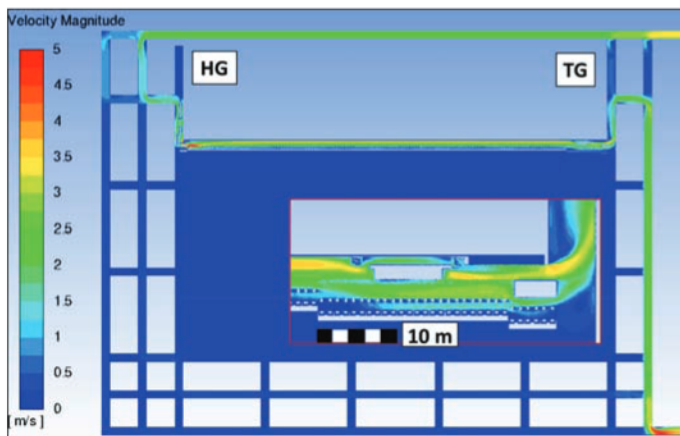


Figure 2. Plan view of face airflow velocity contours. C = curtain, HG = headgate, R = regulator, S = seal, TG = tailgate. Arrows indicate direction of flow.

shearer is cutting near the tailgate (TG) and located between shield numbers 140 and 148 of 152 shields on the face. The inset in Figure 2 provides a detailed view of the flow velocity distribution around the shearer and near the tailgate. Flow obstructions marked in grey represent the coal face, the shearer body, tailgate drive and shield hydraulic jacks.

Figure 2 illustrates the complexity of air flows in the face area. It clearly shows the turbulences caused by sharp turns and obstacles in the flow path. The reference plane 1.5 m above the coal floor was chosen arbitrarily. It should be noted that different flow patterns may occur in other reference planes.

Figure 3 depicts three reference zones where methane content was studied: Zone M1 represents the walkway underneath the support shields where mine examiners typically take air velocity and methane readings using handheld instruments. Zone M2 is in the path of the shearer body, above the face conveyor. Shearer-mounted methane sensors are typically located at the top of the shearer body and operate in this zone. Zone M3 is the top corner area where the concentration of methane released from the freshly cut coalbed is highest and the cutter bits are in contact the roof rock. Zone M3 is a likely location to ignite methane explosions, especially if worn cutter bits leave streaks of hot metal on the roof rock. Zone M3 shifts during the cutting process: prior to cutting coal, M3 is closer to the shields, while after cutting out, M3 shifts away from the shields until the shields are pulled up for the next cut.

Figure 4 shows the average methane mole fraction in percent for each of the three reference zones based on CFD modeling results with the shearer positioned at the tailgate, shield

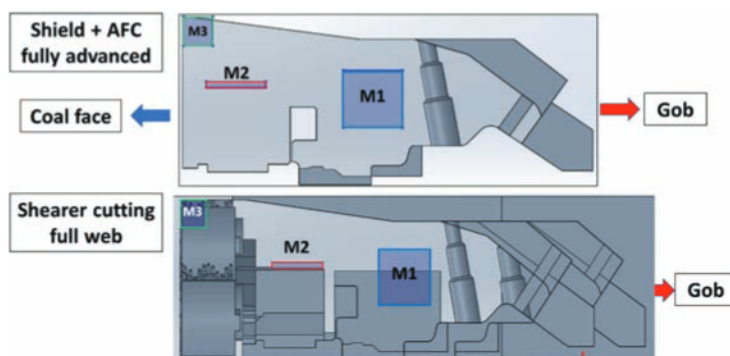


Figure 3. Cross section of the longwall face showing three reference zones for methane detection. Zone M1 is 1 m squared. The top image shows zone M3 after cutting out the coal, while the bottom image shows the same location with the shields advanced for the next cut. View is towards the tailgate.

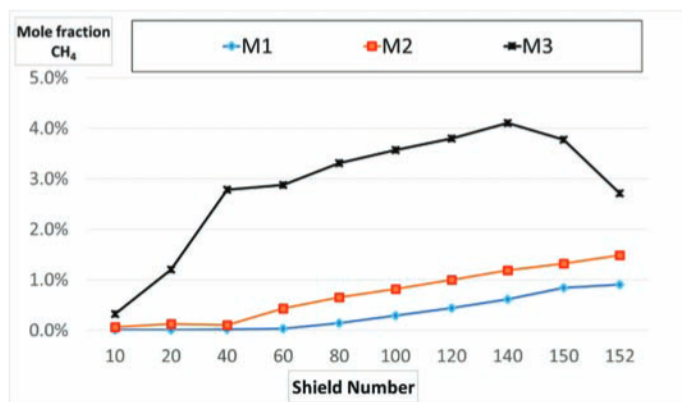


Figure 4. Average methane content in each of the reference zones, plotted over the length of the longwall face from headgate (shield no. 1) to tailgate (shield no. 152).

150. In the CFD models, methane was emitted from the exposed coal face area only. In future models, researchers will include methane emissions from the freshly cut coal on the face conveyor as well as emissions from the gob. The CFD models include realistically represented cutting drums that rotate but do not yet include water sprays. Fresh air entering the longwall face is assumed to have no methane.

From the CFD models, researchers note several key observations about the methane distribution in the tailgate area of the longwall face:

1. Methane concentration increases over the length of the face from headgate to tailgate, following the ventilation air stream. This is caused by two additive effects: the face air quantity decreases over the length of the face because some air leaks into the bleeder ventilated gob. At the same time, methane emissions along the face are cumulative, leading to increasing methane volume over the length of the face. Researchers note that methane distribution may be different for progressively sealed or bleederless gobs as the leakage patterns are different, but the general trend of increasing methane concentrations from headgate to tailgate remains.
2. Referring to [Figures 3 and 4](#), the average methane concentrations are lowest in zone M1. This is expected as M1 is farthest away from the methane source. Based on the CFD model, machine-mounted sensor readings in zone M2 may read 2 to 7 times higher than concentrations measured with handheld instruments in zone M1 at the same shield location. Researchers have yet to study the impact of boundary layer effects on top of the shearer body to determine their impact on machine sensor readings.
3. Methane concentrations in zone M3 are highest. It should be noted that both M3 locations coexist on the longwall face. M3 is assumed to always be in the top left corner of the face, as viewed from the headgate, but its distance to the other zones varies depending on the shearer cut. Both M3 locations are represented in the graph in [Figure 4](#). The M3 location shifts as the shearer cuts, until the shields advance following the shearer cut.
4. Based on the CFD model, methane concentrations in zone M3 are 3 to 30 times higher than those measured in M1. In the current scenario, a handheld examination under shield no. 140 would read 0.6% methane while the concentration in the shearer cutting zone M3 exceeds 4%. It is likely that the shearer would not alarm as it travels towards the tailgate past shield no. 140 where the M2 average does not exceed 1.5%.
5. The peak methane concentration in Zone 3 occurs around shield 140. Methane concentration drops towards the tailgate because the shearer partially obstructs the airflow and increases turbulent mixing and dilution. In addition, the gob plate that prevents gob rubble from entering the face at the tailgate, further obstructs the flow and increases face air velocity, as the inset in [Figure 2](#) shows.

[Figure 5](#) shows a projection of [Figure 4](#) data with methane amounts increased by 25%. With the shearer located at shield 140, the methane sensor in location M2 still would likely

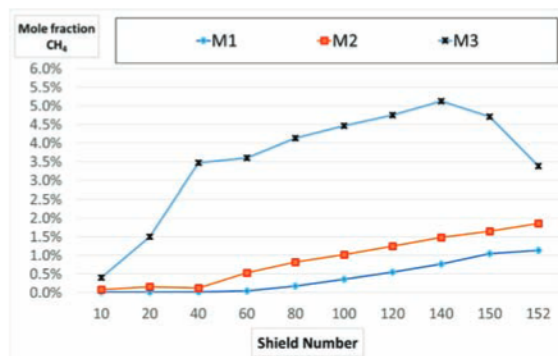


Figure 5. Methane concentrations as presented in [Figure 4](#), with methane inflow increased by 25%. At Shield 140, M2 concentration is 1.5% while M3 is explosive.

not alarm, as the M2 concentration is just below 1.5%. As the shearer continues to travel towards to tailgate, the M2 concentration will exceed 1.5%. Considering that the time lag of the machine-mounted sensor may be 20 seconds or more (see Taylor et al., 2010), the shearer may be well on its way back and snaking in for the next pass by the time the sensor responds. At a speed of 1 m/s, the shearer would advance 10 shields in 20 s. This puts the headgate-side cutter drum near the explosive zone at shield 150, where an explosion hazard exists. At this location, the M3 methane concentration is exceeding 4.5%. It should also be noted that hand-held methane readings in this scenario would read around 1.0% which may not raise concerns if the ventilation plan allows up to 1.5% in the longwall face.

3 A METHANE EXPLOSION HAZARD PROXIMITY MODEL

Rather than relying on one or two point-type methane detectors, future methane monitoring are expected to utilize real-time CFD modeling, supported by remote infrared detectors combined with multiple, strategically positioned point-type sensors. Researchers at the Colorado School of Mines propose a methane hazard proximity model that can detect a cloud of explosive or flammable methane-air mixture and track the explosive zones as they form and move through the face.

Figure 6 shows an MSHA artist's rendering of a flammable methane-air cloud that migrated into the tailgate area of the longwall face at the Upper Big Branch mine, resulting in the 2010 explosion when it reached the shearer as it was cutting sandstone roof with dull bits. The envisioned real-time CFD model of the longwall face would continuously recalculate the air quality distribution in the face area using data from a larger number of point-type and infrared sensors to compute "shells" of the cloud that mark defined methane concentrations limits of interest as the shearer cuts the face area. Using the sensor information, the model computes the source(s) of methane and projects direction of flow and proximity to potential ignition sources such as the cutter drums of the shearer. If the model determines proximity of a flammable gas mixture, specific equipment such as shearer, shields and conveyors will lock out. Lock-outs can be released as soon as ventilation improves and/or the hazardous cloud has passed.

Figure 7 shows a snapshot CFD depiction of the longwall tailgate area with the shearer, drums rotating. The blue shaded envelope marks methane concentrations ranging from 1–2% while the green area illustrates the 2–4% methane range. Near the cutting drums, there are small areas of red shading that indicate concentrations above 4% methane.

The CFD model further confirms that the green and red zones are not "visible" to either the sensor mounted on the shearer or a sensor that would typically be mounted on the tailgate drive and would not be detected with current methane monitoring equipment. Figure 8 shows a different rendering of the CFD model referencing the locations of machine-mounted

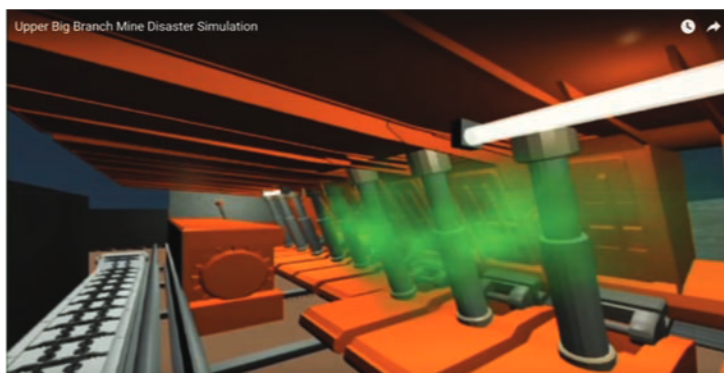


Figure 6. Simulated, flammable methane-air cloud, depicted in green, migrating towards the tailgate of the longwall at Upper Big Branch mine. MSHA.

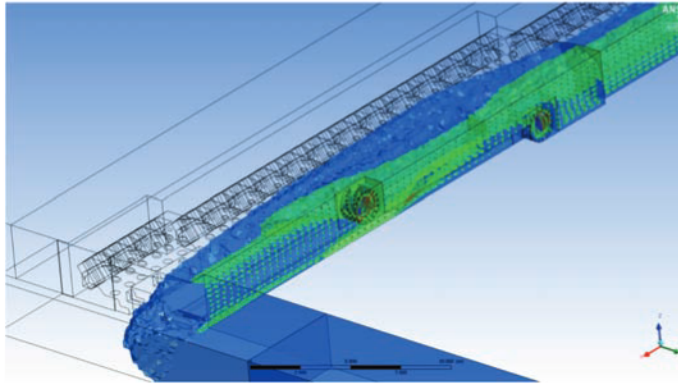


Figure 7. Methane cloud forming around a longwall shearer cutting in the tailgate area. Blue shading indicates methane concentrations between 1 and 2%, green, 2-4% and red, above 4%. Shearer is static with drums rotating and cutting towards the tailgate.

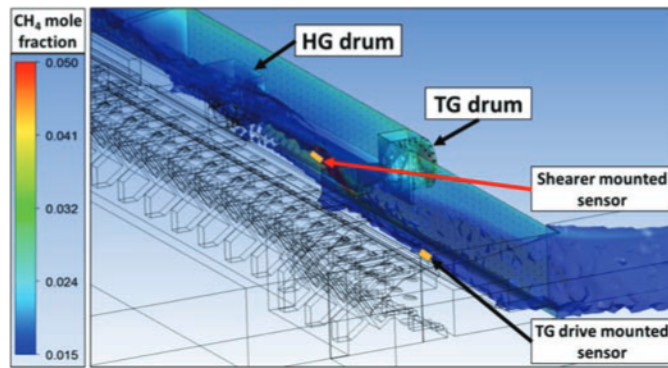


Figure 8. Methane-air cloud around the shearer with mole fractions between 1.5% and 5%, with colors indicated in the legend. The machine mounted and tailgate drive mounted sensors will not alarm as they are not “seeing” concentrations above 1.5%.

sensors on both the shearer and the tailgate drive. The sensor locations were taken from Page et al., 2011). Figure 8 shows that both sensors are outside the colored cloud that marks methane mole fractions between 1.5% and 5%. In this model scenario, neither sensor would alarm as they are both in concentrations below 1.5%. A handheld methane reading taken in Zone M1 would indicate a concentration below 1%.

4 SUMMARY AND CONCLUSIONS

CFD modeling of longwall ventilation and methane concentrations confirms that current practices of manual methane readings as well as machine-mounted methane sensors are likely not capable of detecting explosive methane air-mixtures near the shearer cutting drums. This may explain frequent face ignitions in U.S. longwall mines (Verma and Brune, 2010) and also provide insight into circumstances that led to the 2010 Upper Big Branch mine explosion. Current limits of 1 or 1.5% in the shearer path and/or walkway are not suitable indicators to warn of methane ignition and explosion hazards in the longwall face.

Researchers at the Colorado School of Mines have developed detailed Computational Fluid Dynamics (CFD) models that depict airflow and methane concentrations in the longwall face and generated predictive envelopes of possible methane concentrations around the

shearer. These methane envelopes suggest more meaningful strategic locations where methane sensors should be mounted to provide a more accurate warning of methane explosion hazards. In the near future, as sufficient computing power becomes available, such CFD models will be available in real-time and provide the underpinnings for a proximity detection model where the shearer and other ignition sources can be shut off automatically as an explosive methane cloud approaches. To provide sufficient calibration for the real-time CFD models, researcher recommend to mount methane sensors in the tips of all shields, in zone M3 shown in Figure 3. In addition, directional infrared sensors should be added to provide further calibration for the real-time CFD model that serves to inform of explosion hazards.

Future research also needs to re-visit the methane triggers of 1.0% or 1.5% commonly accepted in the coal industry worldwide. As real-time methane distribution models become reality, mine operators can monitor methane in the mining face to much greater detail. With sensors mounted in locations where their indication is truly meaningful, it may be justifiable to set the alarm and shut-off at higher levels while still providing greater safety and protection against methane ignitions and explosions.

5 FUTURE RESEARCH

CFD real-time methane distribution models will be visualized through virtual and augmented reality (VR, AR) where miners can “see” hazardous methane clouds on display screens and in their heads-up displays. (Sebnem to add a paragraph or two).

ACKNOWLEDGEMENT

CDC-NIOSH has provided funding for this research under contract 211-2014-60050. The authors wish to thank NIOSH for this support.

REFERENCES

- Brune, J.F. and Sapko, M.J. 2012. A Modeling Study on Longwall Tailgate Ventilation, Proceedings, 14th North American Mine Ventilation Symposium, Salt Lake City, UT, June 2012, 6 p.
- Kissell, F.N. 2006. Handbook for Methane Control in Mining, CDC NIOSH IC9486, Pittsburgh 2006.
- MSHA 2011. Clip from Upper Big Branch Mine Accident Scenario Video, MSHA web site <https://arlweb.msha.gov/Fatals/2010/UBB/PerformanceCoalUBB.asp>, accessed 12-17-18.
- MSHA 2013. Program Policy Letter No. P13-V-06, Reissue of P11-V-8; Tests for Methane at the Working Face, Using Extendable Probes or Other Acceptable Means, U.S. Mines Safety and Health Administration, Arlington VA, 2013.
- Page NG et al. 2011. Mine Safety and Health Administration, Coal Mine Safety and Health, Report of Investigation—Fatal Underground Mine Explosion April 5, 2010, Arlington VA, December 2011.
- Page, N.G. et al. 2011. Mine Safety and Health Administration, Coal Mine Safety and Health, Report of Investigation—Fatal Underground Mine Explosion April 5, 2010, Arlington VA, December 2011.
- Taylor, C.D., Chilton, J.E. and Goodman, G.V.R. 2010. Guidelines for the Control and Monitoring of Methane Gas on Continuous Mining Operations, CDC NIOSH IC9523, Pittsburgh, 2010, 69 p.
- United States Code of Federal Regulations, 2019. Title 30 Mineral Resources, U.S. Government Printing Office, 2019.
- Verma, A., Brune, J.F. 2016. Face ignitions in US coal mines and prevention technologies. Preprint no. 16–132, SME 2016 Annual Meeting, Phoenix AZ February 2016.

Proceedings in Earth and geosciences
Volume 3



MINING GOES DIGITAL



Editors:
Christoph Mueller
Winfred Assibey-Bonsu
Ernest Baafi
Christoph Dauber
Chris Doran
Marek Jerzy Jaszczuk
Oleg Nagovitsyn

 CRC Press
Taylor & Francis Group
A BALKEMA BOOK



MINING GOES DIGITAL

Proceedings in Earth and geosciences series

The Proceedings in Earth and geosciences series contains proceedings of peer-reviewed international conferences dealing in earth and geosciences. The main topics covered by the series include: geotechnical engineering, underground construction, mining, rock mechanics, soil mechanics and hydrogeology.

ISSN 2639-7749

eISSN 2639-7757

Volume 3

PROCEEDINGS OF THE 39TH INTERNATIONAL SYMPOSIUM 'APPLICATION OF COMPUTERS AND OPERATIONS RESEARCH IN THE MINERAL INDUSTRY' (APCOM 2019), WROCLAW, POLAND, 4–6 JUNE 2019

Mining Goes Digital

Editors

Christoph Mueller

MT-Silesia Sp. z o.o. Wroclaw, Poland

Winfred Assibey-Bonsu

Gold Fields Ltd., Perth, Australia

Ernest Baafi

University of Wollongong, Australia

Christoph Dauber

Technische Hochschule Georg Agricola, Bochum, Germany

Chris Doran

Mitacom Pty Ltd., Brisbane, Australia

Marek Jerzy Jaszczuk

Silesian University of Technology, Gliwice, Poland

Oleg Nagovitsyn

Kola Research Institute, Russian Federation



CRC Press

Taylor & Francis Group

Boca Raton London New York Leiden

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

A BALKEMA BOOK

CRC Press/Balkema is an imprint of the Taylor & Francis Group, an informa business

© 2019 Taylor & Francis Group, London, UK

Typeset by V Publishing Solutions Pvt Ltd., Chennai, India

Although all care is taken to ensure integrity and the quality of this publication and the information herein, no responsibility is assumed by the publishers nor the author for any damage to the property or persons as a result of operation or use of this publication and/or the information contained herein.

The Open Access version of this book, available at www.tandfebooks.com, has been made available under a Creative Commons Attribution-Non Commercial-No Derivatives 4.0 license.

Library of Congress Cataloging-in-Publication Data
Applied for

Published by: CRC Press/Balkema
Schipholweg 107C, 2316 XC Leiden, The Netherlands
e-mail: Pub.NL@taylorandfrancis.com
www.crcpress.com – www.taylorandfrancis.com

ISBN: 978-0-367-33604-2 (Hbk)
ISBN: 978-0-429-32077-4 (eBook)
DOI: <https://doi.org/10.1201/9780429320774>

Proceedings in Earth and geosciences
Volume 3
Proceedings in Earth and geosciences (Print) ISSN 2639-7749
Proceedings in Earth and geosciences (Online) ISSN 2639-7757