Orientation data from acoustic scanner logs: a case study comparing manual interpretation with automated software

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ABSTRACT: The acoustic scanner tool is widely included with the standard geophysical logging suite in drilling exploration as an efficient and cost-effective means to obtain not only information on the orientation of the horizontal stress field but also accurate orientation data of discontinuities within the rock volume. This case study used acoustic scanner data from 42 drill holes from four different coal deposits that have been interpreted using both manual and automated methods to compare the outcomes. Results of this study demonstrate how the engineering geology of a deposit can be affected by the methods used to interpret the acoustic scanner logs. Manual interpretation of discontinuities accurately reflected true depositional bedding direction and enabled the definition of distinct geotechnical joint sets and accurate fault delineation. Automated software failed to recognise faults, focused on sub-horizontal features, and commonly missed or incorrectly classified discontinuities, thereby missing important geological structures.

1 INTRODUCTION

1.1 *The acoustic scanner*

The acoustic scanner is a geophysical downhole logging tool that generates a high-resolution 360° image of a drill hole wall by transmitting ultrasonic pulses and recording the reflected signal. The amplitude and travel time of the reflected signal are a function of rock properties of the wall and the nature of geological discontinuities, such as bedding, joints and fault planes that are intersected in the drill hole.

Discontinuities are identified from the acoustic scanner digital image where differences in colour, texture and fabric reflect the rock properties and shape of the drill hole wall. Discontinuities can be picked on the image either manually or using software that automatically identifies them based on algorithms.

The purpose of this case study is to compare manual interpretation with automated picking and highlight how the engineering geology model of a coal deposit can be affected by the methods used to interpret the acoustic scanner logs.

2 METHODOLOGY

2.1 *Manual interpretation: the ASIMS method*

ASIMS (a subsidiary of McElroy Bryan Geological Services, MBGS) has developed specific methods for interpreting acoustic scanner logs and analysing resulting data on projects within Australia and around the world (Pell et al. 2014).

An ASIMS interpretation involves an experienced geologist manually identifying only high confidence discontinuities in the scanner log. Each discontinuity is classified according to specific attributes displayed on the image. In cored sections, core photographs and geotechnical logs are referenced to assist in validating the interpreted features, in a method known as integrated interpretation (Fig. 1); also known as hybrid logging (Gwynn et al. 2013, Pell et al. 2014). Classification groups identified include depositional bedding, joints (open, closed/ infilled or discontinuous), caved/ crushed zones and faults. Siderite bands and crossbedding can also be picked when they are clearly visible on the scanner image. Gamma and short spaced density geophysical logs are referenced to assist in identifying bedding and siderite bands.

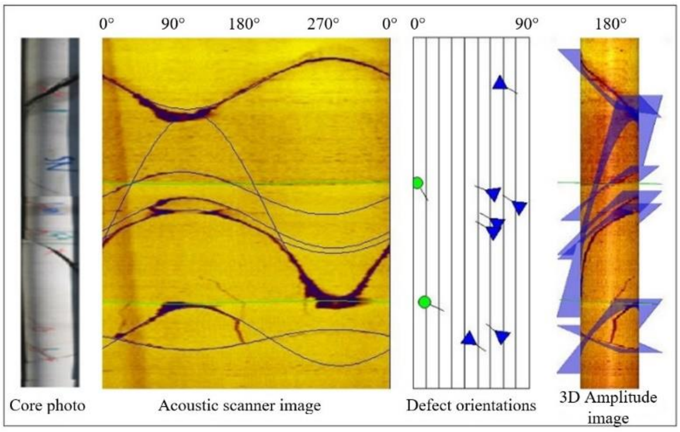

Figure 1. Example of integrated interpretation

The ASIMS classification system was developed by comparing the acoustic scanner log to the core in-situ, where discontinuities visible on the scanner image were located on the core. The appearance of the discontinuity on the image (smoothness, continuity, colour etc.) was noted and those with similar characteristics were assigned a classification.

Manual acoustic scanner interpretation requires an experienced eye that can ‘read’ the strata, understand the relationship between geology and structure, be proficient with geophysical logs and have geotechnical logging experience (Rees & Graff 2013). An experienced exploration geologist has the ideal qualifications necessary to extract accurate orientation data from scanner images in both core and non-core holes.

2.2 *Automated picking*

Several software packages with an automated picking function are now on the market. These use algorithms to identify discontinuities on the acoustic scanner image and a confidence threshold can be applied to filter out low confidence features and noise.

Image quality is crucial for automated analysis; if a scanner image is poor quality, due to borehole wall rugosity induced by drilling and/ or weak strata (particularly in coal), the software will avoid these zones for interpretation (Wedge et al. 2015). However, it is often within these disrupted zones that complex and meaningful orientation data are located and required.

2.3 *Case study*

For this case study, data was sourced from four coal deposits within Australia. Three of these deposits are in structurally benign regions (28 holes), and one is from a structurally complex deposit (14 holes). Benign regions are defined as those having little to no known regional structural influence. Complex deposits are within zones influenced by faulting, folding, intrusive episodes and other structural interference.

Acoustic scanner logs from the 42 boreholes were manually interpreted by ASIMS and compared to data captured by a third party using automated software from the same holes.

Image quality in the benign regions ranged from moderate in non-cored holes to high in cored holes, with minimal noise and generally clear definition of lithological boundaries and discontinuities. In the structurally complex holes, the image quality was low to moderate even in the cored holes, with caving related to structure being the main factor (Fig. 2).

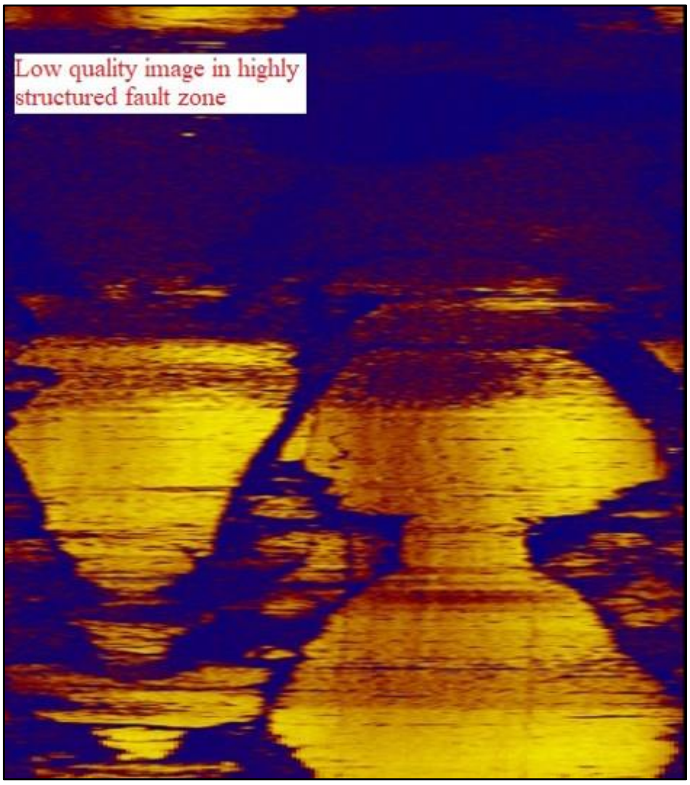

Figure 2. Example of low quality image in a cored section within a structurally complex fault zone

Bedding and joints were identified and classified using manual and automated methods for each borehole. Faults evident in several holes were readily interpreted manually, however automated software failed to detect the associated truncated and/ or displaced strata and were not identified by the automatic process. Data from both methods were plotted on equal angle, lower hemisphere stereonet projections (pole plots), providing a clear comparison of the orientation data for each discontinuity classification.

3 RESULTS

3.1 *Joints and cleats*

The identification of joint and cleat sets is an integral part of mine design and hazard mitigation in both surface and underground mines.

Geotechnical sets are identified as clusters of data on stereonet pole plots from which the average dip and dip direction is obtained. Identifying up to four geotechnical joint sets in a coal deposit is common, occasionally more are identified, typically two or more joint sets are orthogonal, and at least one set generally relates to bedding. Near vertical joints often exhibit a reversal in dip direction caused by small changes in dip angle. This phenomenon creates a range of joint dips across the vertical axis and is referred to as a wrapped data set and is a common feature of many joint sets identified.

The manual interpretations from this study resulted in the identification of distinct geotechnical joint sets from each borehole. These sets were often correlated between holes and traced through complex structural zones as they rotated with bedding near thrust faults and within folded strata (Henwood & Pell 2016). Joint sets within target coal seams (cleat sets) were also easily defined where clear patterns emerged between holes.

Conversely, automated software regularly classified joints incorrectly as crossbedding or bedding (and vice versa) and often missed moderately to steeply dipping joints making the identification of geotechnical sets biased, unreliable and incomplete.

In 22 of the 28 holes (79%) from the benign regions, automated software partially identified one or two geotechnical joint sets that were also found using manual methods but missed other potentially important sets (Fig. 3). In the structurally complex holes, geotechnical joint sets were only partially resolved by automation in just two of the 14 holes (14%).

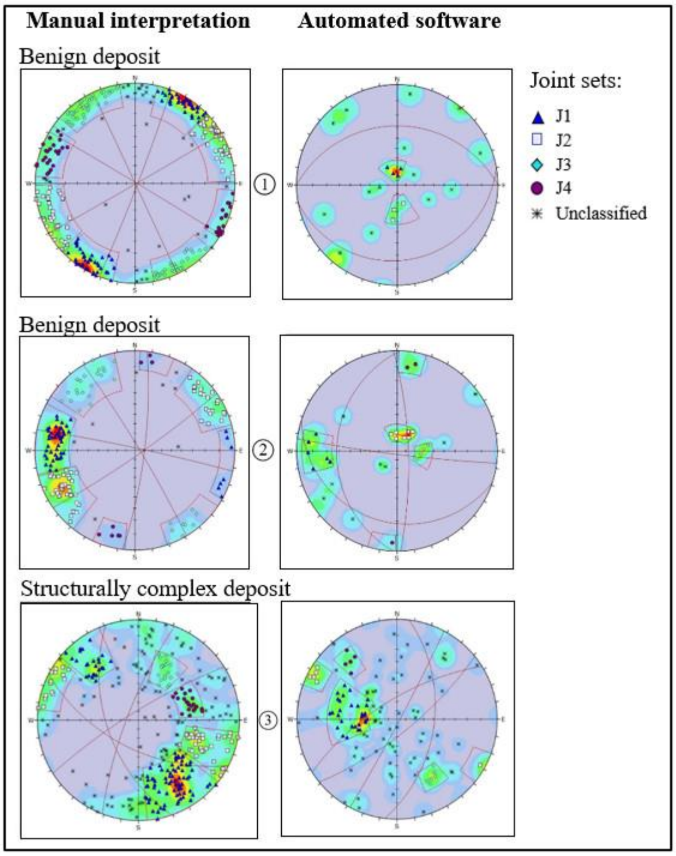

Figure 3. Examples from three drill holes of joint discontinuities and geotechnical sets in benign and structurally complex deposits from manual and automated interpretations

3.2 *Bedding*

In manual interpretation, bedding is defined by coal/stone interfaces and lithological boundaries that can be cross-referenced and validated against the density and gamma logs. This process removes textural elements such as crossbedding from the data set.

Automated software tends to over emphasise sub horizontal features (Thomas et al. 2015) by classifying crossbedding or laminae as bedding, resulting in an excessive number of 'bedding' features with a large orientation range that has no relationship to the in-situ regional bedding of the deposit (Fig. 4). In 27 of the 42 holes (64%), bedding identified by automated software in both benign and complex regions showed no tangible relationship to true regional bedding.

However, in 9 of the 14 (64%) structurally complex holes with higher angle bedding dips, the automated software could identify comparable bedding sets to the manually acquired data, although with slightly less resolution (Fig. 5).

A limitation of currently available automated software is that it cannot cross-reference other geophysical logs to assist the classification of true depositional bedding and therefore avoid mislabeling crossbedding as bedding. In this study, bedding discontinuities classified manually (and authenticated against other logs) were repeatedly mislabeled as low angle joints by the automated process; the software was unable to determine the difference between bedding and low angle joints (Fig. 6).

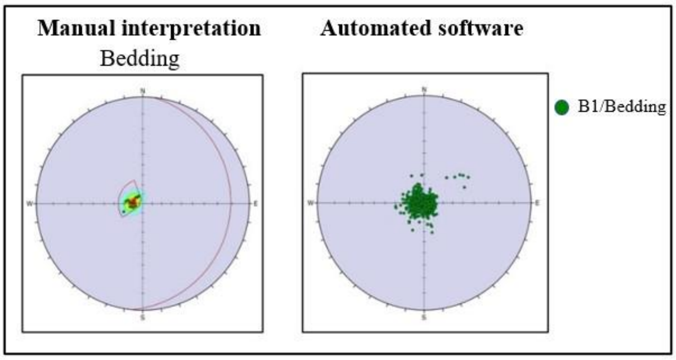

Figure 4. Typical example from one drill hole of over-picking and misclassification of sub-horizontal features as bedding by automated software compared to true depositional bedding classified manually

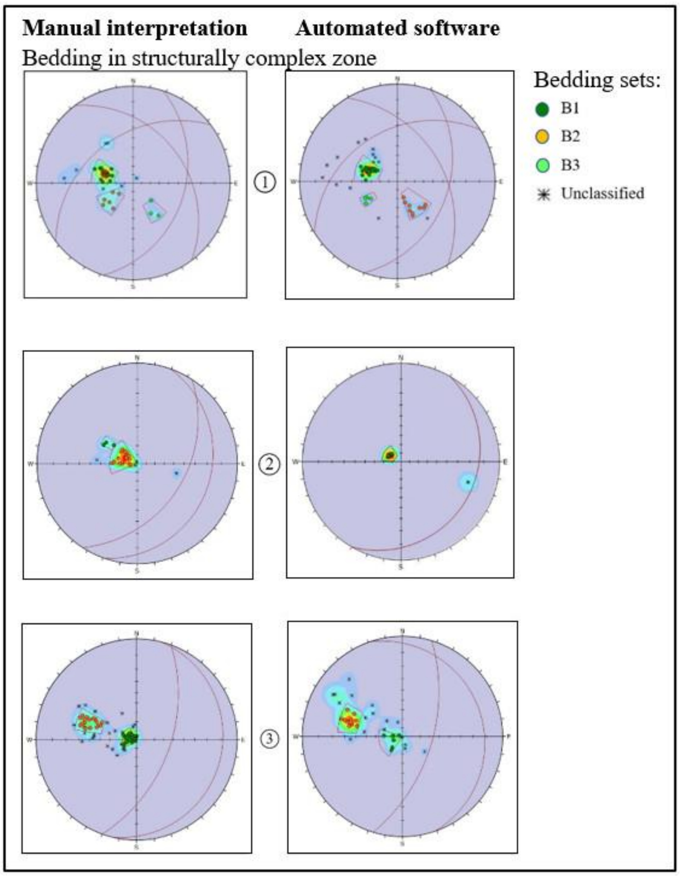

Figure 5. Examples from three drill holes of bedding discontinuities and sets in structurally complex zones using manual and automated methods

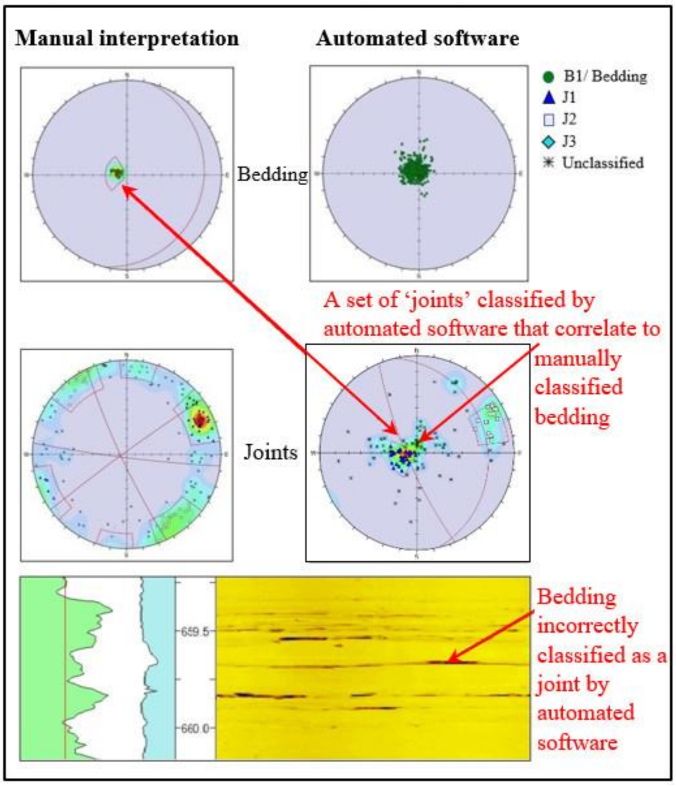

Figure 6. Example from one drill hole of bedding mislabelled as joints by automated software

3.3 *Faults*

Manual interpretation facilitated the identification of faults with a high level of confidence. The experience of the interpreter is an important factor in identifying faults, as it is often difficult to see the displacement and/ or truncation of bedding that is a key indicator. The interpreter can change the colour palette and scale of the image to assist with accuracy of fault delineation, particularly in areas of structural complexity.

Currently available automated software cannot interpret the morphology of the sine curve as it interacts with cross cutting layers (Al-Sit et al. 2015), therefore faults are routinely overlooked or mislabeled as the software struggles to identify displaced and/ or truncated bedding. The complexity of shear zones and the presence of poorer quality data often associated with faulted strata impedes the automated process (Naeini et al. 2018). The automated software did not recognise any of the faults present within the 42 drill holes from this study (Fig. 7).

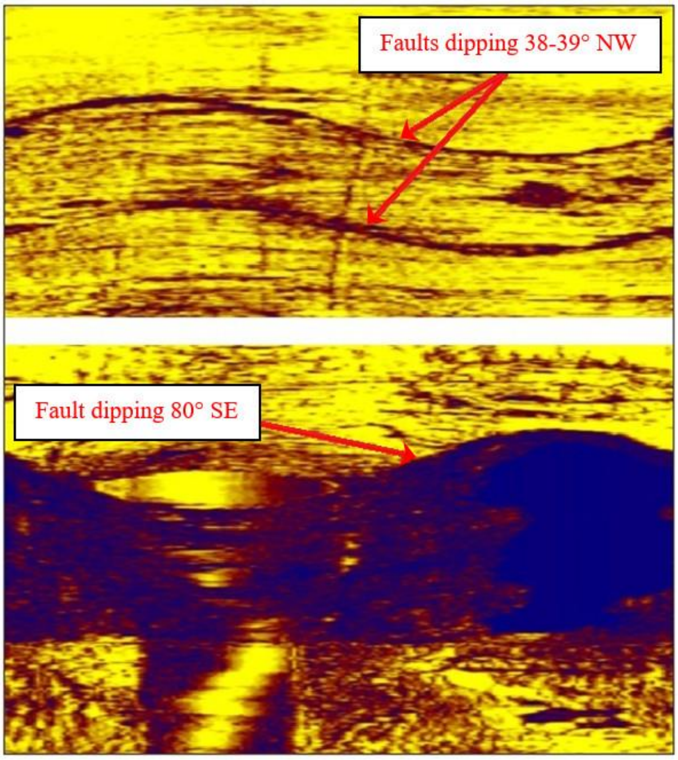

Figure 7. Examples of faults identified by manual interpretation (also seen in core) and overlooked by automated software

3.4 *Complex structural zones*

Accuracy and reliability of data is imperative in deposits with structural complexity. Often, the acoustic scanner logs within these holes are of low to moderate quality, with large areas of disruption, caving and shear zones, where many interacting joints and faults need to be carefully and individually selected. The manual process allows the user to adjust the palette and scale when required, reference core photographs and defect logs if available, and assess the geotechnical components of the zone to produce an authentic interpretation of the bedding, joints, faults and other structures. Figure 8 illustrates how automated software can confuse manually classified bedding (validated against core photographs and density/ gamma logs) for low-angle joints.

Automated picking regularly falls short with areas of structural complexity, where image quality is often poor and individual sine curves cannot be easily resolved. While high angle bedding may be resolved by the automated software in clear portions of the image, joints and faults are inaccurately classified or completely overlooked, making the allocation of meaningful geotechnical sets difficult in these zones.

The consequences of inaccurately picked orientation data in structurally complex deposits may have far reaching implications in mine planning and hazard mitigation.

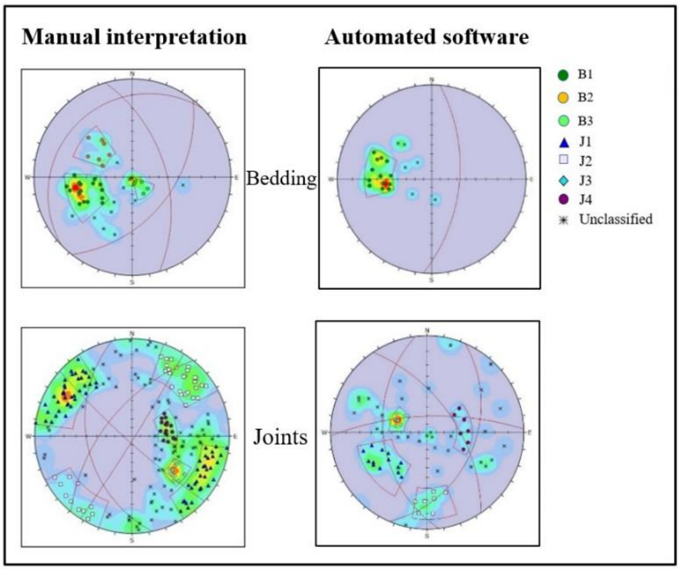

Figure 8. Examples from one drill hole of bedding and joint interpretations in a complex structural zone comparing manual and automated results

4 APPLICATIONS OF MANUALLY INTERPRETED ACOUSTIC SCANNER DATA

Accurately interpreted orientation data from a manual interpretation of acoustic scanner logs has a variety of geotechnical applications relevant to mine planning and development.

Reliable bedding orientation can be imported into the resource model, and the ability of the acoustic scanner to run in vertical holes is particularly valuable in obtaining joint data. Typically, joints will be normal to bedding and it appears that the seam dips are usually large enough that the potential orientation bias inherent with vertical holes is not present.

Incorporating inaccurate orientation data with mine planning and design can ultimately be expensive, time consuming to resolve, and potentially hazardous to the mine. This issue is further accentuated in greenfield exploration prior to the start of excavation, where there are no in-pit or underground joint surveys to reconcile with the acoustic scanner interpretation. Validation can only be achieved once operations commence and as mining progresses.

A major application of acoustic scanner data is in the underground coal mine where decisions on the orientation of roadways and longwall faces should consider aligning outside 20° of strike of the main joint sets (J1 and J2). Gas drainage efficiency may be increased if the holes are aligned to intersect the dominant cleat set within the target seam at an optimum angle. In surface mines, acoustic scanner interpretations provide key information to assist in optimising mining conditions, highlighting areas of geotechnical instability contributing to rock mass failures and reducing hazards (Henwood & Pell 2016).

Acoustic scanner data is invaluable in structurally complex deposits, where highwalls may be exposed to planar slides (if the bedding dips out of the wall) and wedge failures. Flattening of bench face angles or large stand-off distances may be required. Underground coal mines, and especially longwall faces, seek to avoid structurally complex ground. This case study illustrates that manual interpretation is superior for identifying true depositional bedding and accurately resolving joints and faults in complex zones. Reliable data from manual interpretation can confidently be imported into structural models, reducing the requirement for structural delineation drilling, and improving mine planning and development.

5 CONCLUSIONS

This comparison case study has highlighted the importance of manual interpretation in the collection of meaningful geotechnical data from acoustic scanner logs and has demonstrated the limitations which lead to potential hazards of relying on automated software.

Manual interpretation provides a robust and high confidence data set, especially in structurally complex zones or where the image is low to moderate quality, and prior to the commencement of mining. Accurate bedding, joint and fault identification is an integral part of mine planning and hazard mitigation, particularly in underground coal mines, where the orientation of roadways and longwall faces in relation to joint sets must be considered.

Automated software may appear to save time but the results from automated interpretations prove to be highly inaccurate. Automated software has consistently proven to be deficient in the reliable identification of bedding, joints, and faults in both benign and structurally complex coal deposits. Automated picking may have an application in scenarios where there are a large number of joints with a consistent orientation, such as in deep mineral or petroleum deposits where is it not necessary to pick every discontinuity, but a representative selection of joints will suffice. This is not the case in coal deposits, where it is important to pick and classify each discontinuity to define accurate geotechnical sets.

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7 ENDNOTE

The authors would like to acknowledge and thank Ross Seedsman for his contributions to this case study.