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Investigating the anisotropy strength index (ASI) for some Egyptian ornamental stones

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Preliminary communication

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Abstract

The nature of ornamental stones is anisotropic. The heterogeneous characteristics of the anisotropic rocks vary with direction. The highest to lowest strength ratio is known as the anisotropy strength index (ASI). A thorough investigation of the ASI is necessary to determine the best-directed loads for these rocks. On core specimens that have been bored parallel and perpendicular to the weakness planes, this is estimated using both uniaxial compression and point load testing. For this examination, four different rock types had cores that were drilled conventionally and in line with weakness planes. The research shows that drilling cores to weakness planes at a normal or nearly normal angle (90° to 60°) yields the best, most dependable ASI. According to the current study's findings, the ASI fluctuates depending on how uniformly the mineral content and texture of rocks are. A suggested way to calculate the ASI and the load point strength is also included. This study reveals that the employment of ornamental stone as is (for example, precipitation position is more robust and reliable than that perpendicular form) is critical in determining the resilience of this type of rock and its spatial implementation (e.g. flooring).

Keywords:
anisotropy strength index (ASI); uniaxial compression (UCS); point load test (PLT); ornamental stones

1. Introduction

When designing and analyzing rock structures, anisotropy is defined as the differences in attributes with regard to the orientations involved. A rock mass is sometimes referred to as anisotropic because it contains a fracture system that is typically not evenly or regularly distributed and because its behaviour might vary depending on the direction of the force. In terms of their physical and mechanical characteristics, rocks are typically anisotropic. When it comes to mechanical properties, layered rocks typically show varying degrees of anisotropy. The failure process of anisotropic rock is significantly influenced by structural anisotropy (**Zhou et al., 2021**). Sedimentary and metamorphic rocks, whose bedding and foliation, respectively, exhibit anisotropy that is obviously observable. Such rocks had inherent anisotropy, which caused them to behave in anisotropic ways in response to loads in relation to the direction of their weak points (**Yin et al., 2019; Duan et al. 2016; Amadei 1996**). Even though igneous rocks frequently appear to be homogenous and isotropic, in practice, it is clear that many of their properties change depending on the direction of loading during testing. In the subject of rock mechanics and other technical properties, the concept of anisotropy is well-known. A theoretical investigation of the elastic anisotropy of a rock mass with regular joints was the first step in understand-

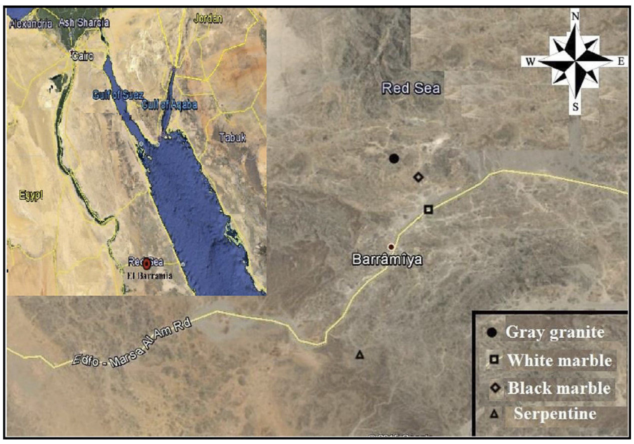

Figure 1: A map of the area under study

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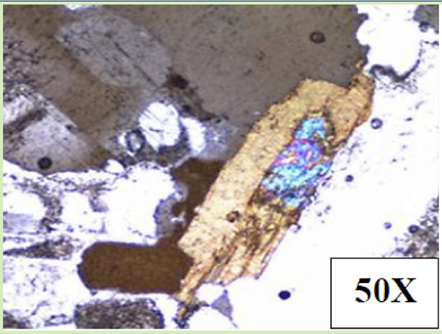
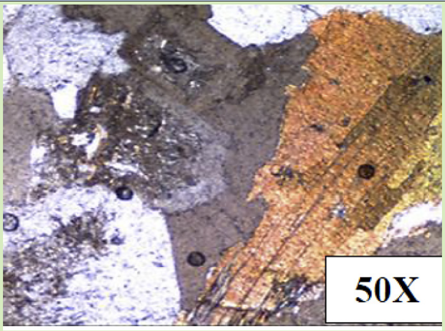
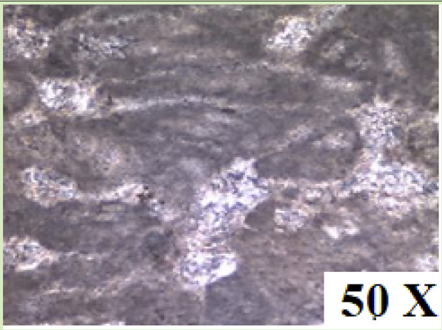
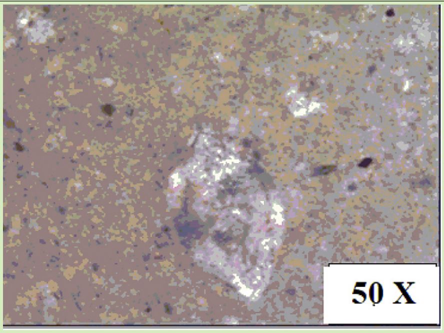
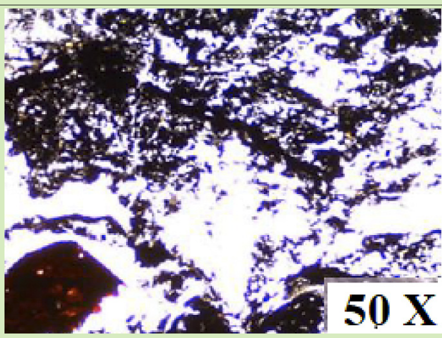
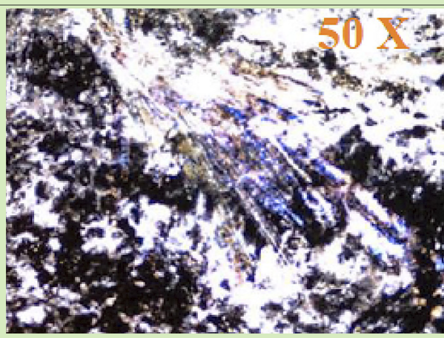
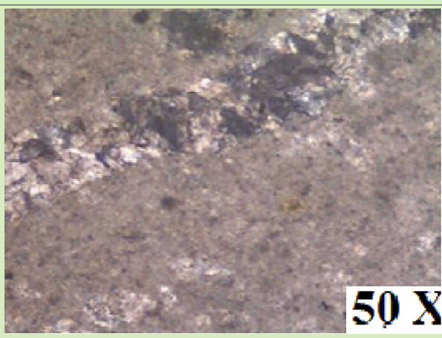
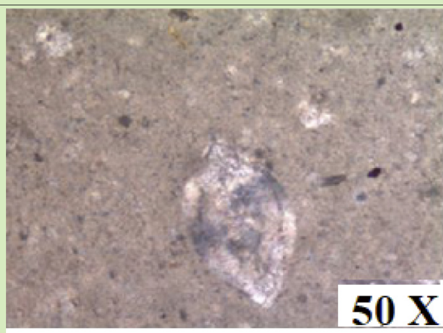
Rock type	Normal 90°	Parallel 0°
Gray Granite		
White Marble		
Black Marble		
Serpentine		

Figure 2: The photomicrograph is normal and parallels with the weakness planes of the studied rocks

ing how joints affect this property (**Morland 1976; Khoshouei et al., 2020**). The significance of rock mass anisotropy is emphasized and the connection between rock anisotropy and stress, deformability, and strength of a rock mass having a regular single joint set is discussed (**Amadei, 1996**). Anisotropy strength and deformability of various rock materials have been studied experimentally and documented in the literature using tiny samples and routine laboratory procedures, such as those provided by (**Reik and Zacas, 1978; Broch, 1983; Chen et al. 2011; Mikaeil et al., 2018**).

Rocks that are entirely isotropic are uncommon and should be viewed as exceptional. Consequently, it is essential to relate the findings of all rock strength tests to the relationship between the orientation of stress and the directions of the tested samples' textures. If applicable, samples should be evaluated under forces that are as great and as directed as those that the rocks at the worksite will experience. Establishing prospective stress conditions for rock is challenging, though. For example, drilling and blasting will put the rocks under extremely difficult stress circumstances (**Yang et al. 1998; Ajal-**

loeian and Lashkaripour, 2000; Nasseri et al., 2003; Arezou et al., 2021; Mikaeil et al., 2021).

Due to the presence of cleavage and weakening planes that allow shear zone initiation, rock isotropy significantly affects the stability of a structure. A numerical solver based on the Fast Fourier Transform could be used to analyse the viscoplastic behaviour of rock (**Ran et al., 2019**).

The highest and lowest strengths of the rock are typically two strength numbers that are of great interest. If collapse is started parallel to - and perpendicular to the rock's weakness planes, accordingly, the highest and lowest strengths are attained. The ultimate strength anisotropy of the rock can be thought of as the proportion between two extremes (**Gonzaga et al., 2008; Cho et al. 2012**).

The purpose of this study is to determine the strength anisotropy of the chosen rocks using the point load strength anisotropy index (Ia), which is described as the ratio of (Is) obtained by testing in both directions perpendicular to the weakness planes. In the presence of anisotropy, this index exceeds unity. The following sections comprise the remaining portions of this paper. The first part of the introduction concentrated on earlier research on this subject. Geographical background and geological relevance are covered in Section 2. Anisotropy, uniaxial compressive (UCS) and estimating ASI using a point load test are covered in Section 3 with thorough justifications. The causes of the load on the anisotropic core are covered in Section 4. Conclusions are reached in Section 5.

2. Location and geological setting

2.1. Location

Four different types of rocks from the Baramiya area of the Egyptian Eastern Desert have been studied in the current investigation, as shown in **Figure 1**. The first variety can be found in the Baramiya region between latitude 25 05' 16.5" and longitude 33 47' 23.02 as grey granite. The second and third types of the chosen rocks, white and black marble, are found in the Wadi Al Miyah marble quarry, which is located between latitudes 25°04' 56.5" and 33°47'49.9", respectively, for the white marble and between latitudes 25°04'23.1" and 33°47'59.9" for the black marble, on the Edfo-Marsa Alam road. Serpentine is the fourth type of stone that has been examined. It is found in the Baramiya region between latitude 25°01'57" and longitude 33°46'37," where serpentinite forms in weak to moderately elevated positions. In order to avoid changed and broken zones, 28 samples of chosen stones were taken horizontally at intervals of roughly 10-15 m. To get new samples, the deteriorated interface components were eliminated, especially from the bottom of the profiles. Each sample represents a block weighing between 20 and 30 kg.

2.2. Geological setting

The Baramiya region in the Egyptian Eastern Desert is home to igneous and metamorphic rocks that have been created in the East African Basin during the convergence of East and West Gondwana and the closing of the Mozambique Ocean. This region is a section of the Pan-African Arabian-Nubian Shield (**Stern, 1994; Kusky et al., 2003**). In Egypt, Sudan, Ethiopia, and Saudi Arabia, these rocks are clearly visible throughout the Red Sea Hills. Where the research region is located in the Egyptian Central Eastern Desert, ophiolitic mélange and associated rocks, as well as underlying molasses-type sediments and late-tectonic volcanic and granitic intrusive materials, compose practically all of the area's geological makeup (**El Ramly et al., 1993**).

2.3. Petrographical analysis

Figure 2 displays the findings of the petrographic and photomicrographic analyses, perpendicular and parallel to the analyzed rocks' weakness planes, respectively.

The descriptions of the petrographic analysis are listed in **Table 1**.

Table 1: The petrographic examination results of the studied rocks

Rock type	Petrographic description
Gray Granite	Plagioclase feldspars (35–40%), quartz (25–30%), potash feldspars (15–20%), biotite and hornblende (10–12%) are included in the composition as necessary minerals, along with rare opaque minerals (1%). Sericite and carbonate minerals have undergone partial alteration. Medium-grained is Coato. It has an equigranular texture. It occurs in a plutonic manner.
White Marble	Calcite and shell pieces from recrystallization make up the composition. Texture dilution (horn felsic). Fine grains of granularity. Low metamorphism grade. Thermal metamorphism is the type that occurs.
Black Marble	Iron oxides from calcined make up the makeup. Texture dilution (Horn Felsic). It has fine to medium granularity. Metamorphism is of a high grade. Regional metamorphism is another form.
Serpentine	Quartz, fossilized shell fragments, iron oxides, and to make up the makeup. Biochemical texturization. Origin: biochemical. Fine to medium grains. Metamorphism grade is high.

3. Anisotropy Strength Index (ASI)

According to the definition of anisotropy, it exhibits distinct values when measured along axes pointing in different directions. This is a characteristic of rocks that

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is inherent. Performing a mechanical Uniaxial compression test can be used to measure it (**Broch, 1983**).

3.1. Uniaxial compression test (UCS)

Once the orientation of the weakness planes to the direction of the primary principal stress is roughly 30º during the uniaxial compression test, minimal strength is attained. The inclination is at its strongest when it is either near 0° or 90°. This signifies that the ultimate strength for the uniaxial compression test is roughly the same for the two major and narrowly quantified orientations, namely parallel to and perpendicular to the weakness planes. Uniaxial compression experiments on dry cores that were drilled parallel and perpendicular to the weakness plane were used to determine the anisotropy strength index (ASI) for the examined rocks, as shown in **Figure 3**. Rock samples were gathered from the Wadi-El-Miah in the Eastern Desert in blocks cut with a diamond saw and prepared in accordance with ASTM guidelines, measuring roughly 20x15x10cm. Including point load and compressive strength tests with 50 samples each, the most important mechanical properties of the examined rocks were determined. The average rock strength, UCS, and PLT, respectively, have been calculated using **Equations 1** and **2**.

Figure 3: Uniaxial compression test machine

The stress value at failure is defined as the compressive strength of rock. It is given by **Equation 1**

$$\sigma c = \frac{F}{A} \tag{1}$$

Where:

σc – Compressive strength of rock, kg/cm²,

F – Applied force, kg,

A – Initial cross-sectional area, cm².

According to the International Society for Rock Mechanics (ISRM), ten cylindrical specimens (D/L) = 1:2 of each type of stone are prepared by a disk saw machine. Specimens were drilled parallel and normal to the weakness plane.

Table 2 lists the Anisotropy Strength Index (ASI) values that were determined using a uniaxial compression test.

While some researchers believe the strongest cores to be those bored perpendicular to the weakness planes, others report that the strongest cores are those parallel-drilled to the weakness planes. One can mistakenly believe that material is anisotropic based on uniaxial compressive strengths determined on cores bored parallel and normal to weakness planes.

It takes a lot of time and effort to test specimens that have been drilled in different orientations relative to the rock's weakness plane in order to determine the ultimate strength anisotropy (ASI) in compression.

3.2. Estimate ASI using Point Load Test

The invention of **Reichmuth D. (1967)** is when the point load test first appeared; it was condensed into its current form by **Broch and Franklin (1972)**. As depicted in **Figure 4**, a chunk of stone is placed within two conical platens of a mobile lightweight tester as part of an index test for classifying the strength of rocks. The fundamental techniques for evaluating and calculating the point load strength index have been created by the International Society of Rock Mechanics. Axial, diametric, block, and lump point load testing are the four most common forms (**ISRM, 1985**).

Using the point load test apparatus shown in **Figure 4**, the specimens' point load strength was evaluated. Core cylinders measuring 5.0 cm in diameter and 7.5 cm in length (length to diameter ratio: 1.5: 1) were used as test specimens in order to ensure that the end faces were smooth and perpendicular to the longitudinal axis of the specimens.

Table 2: Anisotropy strength index calculated from mean strength for the tested rocks by uniaxial compression test

Rock type	parallel-drilled cores	Perpendicular-drilled cores	Anisotropy *Ia*
Gray Granite	796.45 ± 18.43	895.467 ± 20.34	0.89
White Marble	331.1 ± 4.283	433.2 ± 31.71	0.76
Black Marble	298.43 ± 10.15	378.59 ± 34.24	0.79
Serpentine	400.63 ± 4.924	454.03 ± 18.448	0.89

The load is raised until failure happens within 10 to 60 seconds, at which point the failure load (P) is recorded. After statistical analysis of the experimental results, the average point load strength, mean, standard deviation, and coefficient of variation were determined.

3.2.1. Procedure of diametrical load point test

1. Core samples eligible for diametrical testing have a length/diameter ratio greater than 1.0.
2. It is ideal to perform at least 10 tests on each sample; if the specimen is heterogeneous or anisotropic, additional testing is required.
3. After inserting the sample into the testing device, the platens are shut to interact directly along the core diameter, making sure that the distance L between the contact points and the closest freed end is at most 0.5 times the core diameter.
4. The breakdown load P is measured when the load is gradually raised until failure occurs within 10 to 60 seconds. If only one loading point is traversed by the crack tip, the experiment should be dismissed as erroneous.

The point load test could be completed quickly on both standard rock cores and irregular small stones, as shown in **Figure 4.** The point load strength index (I_S) is determined using the failure load, the distance D between the cone ends, and the rising load until it reaches the point of failure. **Equation 2** defines the uncorrected point load strength index (I_S):

Figure 4: Point load test machine

$$I_S = P / D_e^2 \tag{2}$$

Where:

D_e - is the equivalent diameter of the specimen, cm^2,

P - is the load applied, kg.

The diametrical test (De = D) is used. The minimal cross-sectional area A of the platen-passing plane is calculated using **Equation 3** as follows:

$$A = WD \tag{3}$$

For the block, axial, and irregular lump tests. As a result of the finding that (I_S) rises with (De), it is essential to establish a distinct point load index for the rock sample that could be applied to the categorization of rock strength. The proportion of the adjusted mean strength indices for tests conducted perpendicular and parallel to planes of weakness can be used to calculate the anisotropy strength index (Ia). Values of Ia are greater for anisotropic rocks and nearer to 1.0 for isotropic rocks.

The values of ASI that are computed from the average rock strength determined using a point load test are listed in **Table 3.**

According to **Table 3**, in a point load test, anisotropy strength index values rise by (25–64%) when loading typically to parallel weakness planes.

4. Application of the load on anisotropic cores

It's crucial that the loads are applied properly when testing anisotropic rock cores with a point load device. The load must always be applied in such a manner that failure begins perpendicular to and parallel to the weakness planes (bedding/foliation) in order to get measurements of the highest and lowest strength values. Specifically, for cores bored at an oblique angle to such weakness planes as depicted in **Figure 5**, which shows the proper and improper methods for applying the load. The load for the diametrical test should be placed along the elliptical weakness plane's shortest axis to shield yourself from the repercussions of the uncontrolled shape. Core bits that are shorter than the diameter should be used. Once the load is applied properly, the angle of the weakness planes has no effect on the diametric point load strength; instead, it only has an impact whenever

Table 3: Anisotropy strength index (ASI) calculated from mean strength for the tested rocks by diametrical point load test.

Rock type	Diametrical I_S (kg/cm^2)		Anisotropy *Ia*
	Cores drilled parallel	Cores drilled normal	
Gray granite	148.6 ± 1.36	98.05 ± 8.87	1.52
White marble	58.44 ± 1.38	46.86 ± 6.52	1.25
Black marble	101.71 ± 1.86	62.02 ± 4.37	1.64
Serpentine	62.82 ± 3.02	44.96 ± 4.56	1.41

 pp. 41-48, DOI: 10.17794/rgn.2023.1.4

the planes are between 30 and 60 degrees away from the core axis.

When the formation is inclined by about 30 or so degrees to the direction of the major principal stress, the minimum strength is obtained in the uniaxial compression test. The inclination should be close to 0° or 90° to achieve maximum strength. One might mistakenly believe that a material is anisotropic based on uniaxial compressive strengths measured on cores drilled parallel and normal to the formation. Test specimens that have been drilled in different directions relative to the formation of the rock are required in order to obtain an accurate value for the maximum strength anisotropy in compression. Such a process is both time-consuming and costly. When testing anisotropic rock cores with a point load apparatus, it's crucial that the load is applied properly. When applying the load, make sure that failure starts parallel to and normal to the formation in order to get accurate readings of the maximum and minimum strength values. After diametric point-load tests along the formation run, the results show the best loading direction for cores that have undergone axial point-load tests. The load for the diametral test should be applied along the elliptic formation's shortest axis to prevent the effects of the uncontrolled shape. According to the findings, ornamental stones must be laid out as they were in the field for all applications because the most reliable strength is obtained when loading is consistent with the formation of the rock. Due to the time consuming process, cost and personal error in experimental work, rock characteristics could serve as input parameters for numerical modelling software like PFC (Particle Flow Code).

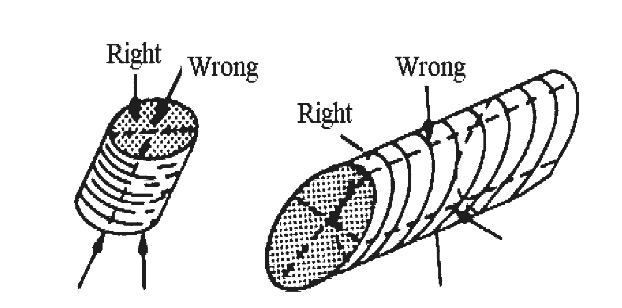

Figure 5: Right and wrong applications of point load test on cores drilled on an oblique angle to the weakness plane (**Saroglou and Tsiambaos, 2006**)

5. Conclusions

The anisotropy strength index, ASI, is employed to determine the appropriate loading direction. When the formation is approximately 30 degrees inclined to the direction of the major principal stress during the uniaxial compression test, the minimum strength is attained. The inclination is at its strongest when it is either close to 0° or 90°. In uniaxial compression and point load tests, values of ASI increase when loading normally to weakness planes against parallel. Due to marble's homogeneous characteristics in chemical compositions and rock texture, as shown by the petrographic analysis, granite and serpentine have lower ASI than marble, especially when using uniaxial compression. The following is the suggested method for calculating the ASI for a core sample tested by a point load apparatus:

1. drilling should be carried out as closely as possible and with deviations of no more than 30 degrees from the rock's bedding and foliation planes,
2. to prevent the water content of the rock from evaporating, cores that are not analysed right away after drilling should be preserved in a specific way.

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SAŽETAK

Istraživanje indeksa anizotropije čvrstoće određenoga egipatskog ukrasnog kamena

Priroda je ukrasnoga kamena anizotropna. Heterogene karakteristike anizotropnih stijena variraju prema smjeru promatranja. Omjer najveće i najmanje čvrstoće poznat je kao indeks anizotropije čvrstoće (ASI). Kod korištenja takvih stijena potrebno je temeljito istraživanje ASI-ja kako bi se utvrdio najbolji smjer opterećenja. To se procjenjuje kod ispitivanja jednoosne tlačne čvrstoće i kod ispitivanja indeksa čvrstoće opterećenjem u točki na jezgrama koje su bušene paralelno i okomito na ravnine oslabljenja. Istraživana su četiri različita tipa stijena čije su jezgre izbušene uobičajeno paralelno s ravninama oslabljenja. Istraživanje pokazuje kako bušenje jezgri do ravnine oslabljenja pod normalnim ili gotovo normalnim kutom (90° do 60°) daje najbolji, najpouzdaniji ASI. Prema rezultatima ovoga istraživanja ASI varira ovisno o ujednačenosti sadržaja minerala i teksture stijene. Također je predložen način izračunavanja ASI-ja koji uključuje indeks čvrstoće opterećenjem u točki. Ovo istraživanje otkriva da je upotreba ukrasnoga kamena po smjeru (na primjer, paralelni je smjer robusniji i pouzdaniji od okomitoga smjera) presudna u određivanju otpornosti ove vrste stijena i u njezinoj prostornoj primjeni (npr. u popločavanju).

Ključne riječi:
indeks anizotropije čvrstoće, jednoosna tlačna čvrstoća, indeks opterećenja u točki, ukrasni kamen

Author(s) contribution

Ahmed Shohda (Ph. D. candidate) gathered rock samples, collaborated on all experimental work with Waleed Draz (Associate professor of Mining Engineering), Faisal Ali (Associate professor of Mining Engineering) and Mahrous Ali (Associate professor of Mining Engineering), and evaluated the results. Mohamed Yassin (an Emeritus professor of Mining Engineering) reviewed the draft manuscript and provided technical suggestions. The entire work was written collaboratively by all of the authors.