INTRODUCTION

Oxidation of pyrite can significantly affect properties and the behavior of soil and rock in civil construction. Case histories of heave due to oxidation of pyritic shale have been reported and continue to be reported worldwide. Examples include widespread structural damage in Pittsburgh, Pennsylvania (Dougherty and Barsotti 1972), and Ottawa, Canada (Morgenstern 1970; Penner et al. 1970); embankment fill problems at Carsington Dam in Derbyshire, United Kingdom; and differential movement of floors and walls of a multi-million dollar school built in Kentucky during the late 1990s, occurring three years after construction was complete (Partridge 2000). It is sometimes claimed in such cases that pyrite-induced heave was an unknown phenomenon and could not have been anticipated, or the damage is attributed to other causes.

Problems with pyritic soil and rock extend globally and across many disciplines. In addition to heave, consequences of pyrite oxidation include concrete degradation, steel corrosion, environmental damage, acid mine drainage (AMD), and accelerated weathering of rock with concomitant effects on strength and stability. Affected disciplines include soil science, mining, engineering geology, geochemistry, environmental engineering (especially water quality), and geotechnical engineering. While pyrite problems may be well known in their respective disciplines, there has been to date relatively little cross-disciplinary communication regarding problems with pyritic soil and rock. Researchers in geology and soil science, for example, have made major contributions to our understanding of acid mine drainage (Caruccio 1988; Skousen and Ziemkiewicz 1996; Evangelou et al. 1998; Barnhisel et al. 2000). It is not commonly realized, however, that extreme geotechnical consequences (e.g., heave) result from the very same chemical processes. Thus, there is a significant need to establish an inter-disciplinary and inter-regional awareness regarding the effects of pyrite oxidation and their prevention or mitigation.

The combined average annual losses resulting from natural disasters such as floods, earthquakes, tornadoes, and hurricanes constitute less than half of the damages incurred by expansive soils, such as those containing pyrite or expansive clay minerals (Dubbe et al. 1984). While extreme amounts of attention and money have been directed toward the control and mitigation of floods, earthquakes, etc., the efforts directed toward the damage to structures caused by expansive soil and rock are much more varied. In some regions, these problems are well known and considerable money and effort are being spent on mitigation. However, in other regions, damage from expansive material is either not recognized or attributed to some other causes, such as differential settlement, poor construction, or frost heave (Dubbe et al. 1984).

The need for an inter-disciplinary awareness regarding pyrite problems relates well to a poem, *The Blind Men and the Elephant*, by John Godfrey Saxe (1816-1887). This poem tells the story of “six men to learning much inclined, who went to see the Elephant (though all of them were blind), that each by observation might satisfy his mind” (Saxe). However, since each of them touched a different part of the elephant, the elephant was described as a wall (corresponding to the elephant’s side), a spear (his tusk), a snake (his trunk), a tree (his knee), a fan (his ear), and a rope (his tail). Thus, each man was left with an extremely different interpretation of the exact same thing. Correspondingly, many people in different disciplines may be familiar with extremely different interpretations and effects of the pyrite oxidation process.

The study of pyrite and related environmental issues date back several thousand years. The degradation of pyrite to acid and salts was mentioned by Theophrastus (ca. 315 B.C.), and Pliny (23-79 A.D.) studied the leaching of pyritic rock to produce “oil of vitriol (sulfuric acid), vitriol (ferrous sulfate), and alum (aluminum sulfates)” (Nordstrom and Alpers 1999). While acid mine drainage (AMD) effects of pyrite oxidation have been issues of concern in the United States since before 1900 (Nordstrom and Alpers 1999; Barnhisel et al. 2000), the geotechnical effects are a much more recent concern. One of the first recorded incidences of pyrite-induced heave occurred in Pennsylvania in 1950 (Penner et al. 1972). However, geotechnical problems with sulfidic materials remained relatively undocumented until the early 1970s when now-classic formative studies on this subject were performed (Morgenstern 1970; Penner et al. 1970; Quigley and Vogan 1970; Dougherty and Barsotti 1972; Grattan-Bellew and Eden 1975). Current studies on these problems can be found in a wide range of more recent publications (Hawkins and Pinches 1992a; Cripps et al. 1993; Mesri et al. 1994; Belgeri and Siegel 1998; Chigira and Oyama 1999; Yamanaka et al. 2002).

Scope of Report

The purpose of this report is to combine information from various sources, disciplines and regions in an attempt to identify and describe geotechnical problems with pyritic rock and soil. The basic physicochemical processes involved with the pyrite oxidation process and the resulting consequences for geotechnical systems are summarized (Section 1). Case histories involving several of these consequences are included to establish evidence of the broad range of affected areas and problem types (Section 2). Guidelines for anticipating problems are outlined to help with the identification of problem formations and their associating visual clues (Section 3, Appendix E). Guidelines for practitioners summarize recommended procedures for site evaluations, estimated magnitudes and rates of the effects of pyrite oxidation, and possible mitigation options (Section 4, Appendices A & C). A survey was conducted to solicit input on the specific types of geotechnical problems encountered that are associated with pyritic materials and to determine which types of mitigation options and specific references are used in various regions (Appendix B). This survey was sent to representatives of each state Department of Transportation and Geological Survey office and to several geotechnical engineers and geologists from various regions in the U.S. and Canada. Five appendices are attached, regarding mitigation options, results of the survey of practitioners, chemical test procedures, a glossary, and visual identification of sulfidic geomaterials.

1 PHYSICOCHEMICAL PROCESSES AND CONSEQUENCES FOR GEOTECHNICAL SYSTEMS

1.1 Chemical reactions and attendant biological and physical processes

The alteration and stability of sulfur-bearing materials are major issues in the fields of geotechnical engineering and civil construction. These materials are problematic in both soil and rock. A basic understanding of the chemical processes involved in the alteration of sulfur-bearing materials is necessary to understand, anticipate, and mitigate problems. The degree of future oxidation and resultant weathering possible in a sulfur-