1.0 INTRODUCTION

Mining operations and practices have important implications for monitoring the Comprehensive Test Ban Treaty (CTBT). Seismic signals from legitimate mining operations can have the ambiguous appearance of being caused by small clandestine nuclear explosions, so confidence-building measures are needed for international treaty monitoring (Taylor, 1994; Walter et al., 1996; Richards, 1997; Committee on Seismic Signals from Mining Activities, National Research Council, 1998). There are distinct challenges, however, to understanding the causes, and discriminating the mechanisms, of seismic energy release in mining environments in the western U.S. and elsewhere. Problematic events include, for example, panel collapses in the Solvay trona mine in southwestern Wyoming in February 1995, which was associated with an M_L 5.2 seismic event (Pechmann et al., 1995; Swanson and Boler, 1995), and underground failures in coal mines in Utah in 1981 (Taylor, 1994) and 1993 (Boler et al., 1997) that produced seismic events in the magnitude (M_L) 3 range.

Mining seismicity is a prominent feature of seismic activity in the Utah region. Besides blasting at surface mines, intense seismic activity is associated with areas of extensive underground coal mining along the arcuate crescent of the Wasatch Plateau (WP) and Book Cliffs (BC) coal fields (Figures 1-1 and 1-2; see also review by Arabasz et al., 1997). The WP-BC region is notable as one of two areas in the western U.S. (the other, the Coeur d'Alene metal mining district of northern Idaho) where mining-induced seismicity is well documented (Wong, 1993). For international monitoring, seismic signals from rockbursts, coal bumps, and mine collapses are more likely to be ambiguous than those from surface blasting (Committee on Seismic Signals from Mining Activities, National Research Council, 1998). Rockbursts and mining tremors of magnitude (M_L) $\leq$ 4.2 have been instrumentally recorded in the WP-BC region since the 1960s. About 27 million short tons of coal are produced annually from this region, with longwall-mining methods accounting for 75 percent of the total production (Jahanbani, 1999).

Given the significant level of seismic activity associated with active underground coal mining in the WP-BC region, seismic monitoring and the characterization of seismic events in this region are of interest both to the University of Utah Seismograph Stations (UUSS), for earthquake research and mine safety, and to Lawrence Livermore National Lab (LLNL), for research and development relating to the Comprehensive Test Ban Treaty. This cooperative project was undertaken to assist LLNL researchers in the latter role.

1.1 OBJECTIVES AND SCOPE OF WORK

This study had three basic objectives:

1. Strategically install a 3-component broadband digital seismic station in the WP-BC region to ensure the continuous recording of high-quality waveform data. The aim was to meet the long-term needs of various interested parties—including LLNL, UUSS, mine operators and others in the state of Utah, and the international CTBT community at large.

2. Determine source mechanisms—to the extent that available source data and resources allowed—for comparative seismic characterization of stress release in mines versus earthquakes in the study region.

3. Gather and report to LLNL local information on mine operations and associated seismicity, including "ground truth" for significant events.

The time period for this project was originally set for a 12-month period beginning February 28, 1998. Due to unexpected health problems affecting one of the principal investigators (JCP), no-cost extensions were agreed upon which ultimately changed the ending date of the project to September 1, 2000.

Funding for Objective 1 accounted for 60 percent of the total budget; funding for Objectives 2 and 3 accounted for approximately 25 percent and 15 percent, respectively. In addition to the awarded amount of $58,960 for this study, UUSS to date has contributed more than $20,000 to this project. LLNL provided funds for more than 90 percent of the equipment costs; UUSS provided the remainder together with engineering and technical personnel for installing and operating the broadband digital seismic station as well as funds to meet ongoing costs for telemetry, maintenance, and operation of the broadband station. Thus, this project truly has been a cooperative one between LLNL and UUSS.

The scope of work to meet Objective 1 involved all aspects of achieving what might be referred to as an "end-to-end" seismographic system—variously involving: (1) engineering, site construction, and equipment installation at the field site; (2) completion of a continuous telemetry connection from the field site to the UUSS central recording laboratory in Salt Lake City, 216 km away; (3) calibration of the complete broadband station system; and (4) continuous recording, processing, and archiving of the digital data. Significant effort on the part of the Principal Investigators was required to oversee each of the above and to perform the system calibration, described in section 2.2.

Following guidance from LLNL's Technical Representative for this contract, William Walter, the focus of Objective 2 was changed slightly to place emphasis on three mining-related events that occurred in and near the study area after the original work plan had been made, thus posing new targets of opportunity. These included a magnitude (M_L) 3.8 shock that occurred on February 5, 1998 (UTC date) just prior to the start of this project, and a magnitude (M_L) 4.2 shock that occurred on March 7, 2000 (UTC date). Both these events originated close to active mine workings in the Book Cliffs area. The M_L 4.2 event was the largest mining-related seismic event instrumentally recorded in the WP-BC area since monitoring began in 1962. The third seismic event of special interest was a magnitude (M_L) 4.3 shock that occurred on January 30, 2000 (UTC and local date), associated with a panel collapse at the Solvay trona mine in southwestern Wyoming—the same mine in which a larger and earlier collapse event in February 1995 attracted considerable attention from the CTBT community, prompting joint study by UUSS and LLNL seismologists (Pechmann et al., 1995).

Also following guidance from William Walter, emphasis on Objective 3 was placed on providing LLNL with information on mining seismicity in the study area that would extend and update the information published by Arabasz et al. (1997). The latter study included seismicity data through March 1996 and comparisons of seismic data with levels of coal production for the period January 1978 through December 1994.

We proceed to describe results relating to the three basic objectives of this study in the following order. First, in section 2, we address Objective 1 (installation of a 3-component broadband digital seismic station. Next, in section 3, we describe results for Objective 3 (information on mine operations and associated seismicity) in order to present necessary background information before addressing Objective 2 (source mechanisms of significant seismic events) in section 4.