

Eolian Hazard Assessment for the SNORT Facility

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Naval Air Warfare Center Weapons Division

FOREWORD

This report documents the study of wind transported and deposited sediments and landforms in the vicinity of the Supersonic Naval Ordnance Research Track at the China Lake Ranges. Wind-blown sand and dust are significant surface processes that may negatively affect the operations and long-term sustainability of the test and evaluation mission of the Naval Air Warfare Center Weapons Division (NAWCWD) by creating significant hazards to personnel, equipment, sensors, aircraft, and civil infrastructure. China Lake has experienced the impact of dust storms for many years. In the past, most of the effects were from dust emitted from the bed of Owens (Dry) Lake to the north, which resulted in restriction of flight operations at China Lake as documented in "Dust Storms from Owens and Mono Valleys, California" (NWC-TP-6731). With the initiation of dust control measures at Owens Lake after 2000, the source of this external dust source has reduced, emphasizing the importance of local sources of dust, which may be enhanced by surface disturbance and/or lowered groundwater levels, and movement of sand by wind.

The work upon which this report is based has been conducted as part of NAWCWD Range Sustainment Office's continuing efforts to define and mitigate potential mission encroachments. The work outlined in the report is intended to both help mitigate future impacts to the NAWCWD China Lake Research, Development, Test, and Evaluation (RDT&E) mission, and to also provide data to enable informed decisions relative to planning and conduct of range operations.

This report has been reviewed by M. L. Boggs.

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08 May 2019

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KEY SCIENTIFIC FINDINGS AND THEIR MANAGEMENT SIGNIFICANCE

Field, office, and laboratory studies of eolian (wind transported and deposited) sediments and landforms in the vicinity of the SNORT Facility were conducted to provide the Naval Air Warfare Center, Weapons Division with the information needed to: (1) assess the sand and dust hazards to existing and planned facilities in the vicinity of SNORT and (2) develop sustainable long-term mitigation and control of sand encroachment and dust emissions to protect these facilities.

Major findings are as follows:

- Currently existing sand dunes and sand sheets are largely stabilized by vegetation and have not significantly changed shape and location over the period for which aerial photographs and satellite images are available (1948 to 2015).
- Dune activity as measured by the sum of areas of erosion and deposition has varied over the period of record, reaching a maximum in the period 1971-1984. The rate of change in dune activity shows a correlation with an index of El Niño strength, with higher dune activity in periods of stronger El Niño conditions. This index of El Niño strength is interpreted as an index of storminess - meaning increased occurrence of strong, sand-moving, winds in the area.
- Sand encroachment onto roads and other facilities is limited to the north end of the SNORT alignment and sections of the Baker Access Road adjacent to the dune area.
- Where disturbance has occurred (e.g. KTM trench location) change is significant and has resulted in the formation of new parabolic dunes, which have migrated up to 400 m (1312 feet) to the east at rates of up to 6.43 m (21 feet) per year.
- Localized contemporary (recent) dune destabilization is occurring as a result of die-off of groundwater-dependent vegetation, leading to the creation of blowouts that are eroding the dunes.
- The mineral composition of sand in the SNORT area indicates that it was derived from the Sierra Nevada, and was transported to the study area by ephemeral washes during two periods of sand deposition at around 0.92–1.22 and 2.0–2.14 thousand years ago (ka). Little or no sand currently reaches the study area through ephemeral stream transport.
- The sand comprising dunes in the study area contains a significant (5-10%) content of fine silt- and clay-size material. If the vegetation that stabilizes the dunes today were to be diminished by drought or groundwater decline, the dunes could become mobilized, and the consequent movement of sand could release large amounts of airborne dust.
- The formation and occurrence of dunes and sand sheets in the SNORT study area is strongly influenced by the position of the groundwater table, which in turn is controlled by the location of the active Little Lake fault zone (LLFZ) and the Airport Lake fault zone (ALFZ). Vegetated sand dunes have accumulated in two discrete areas that coincide with the graben (i.e., pull-apart basin) of the LLFZ and ALFZ, and the axis of the broad fluvial plain west of the graben and SNORT. The eastern area of dunes is covered by a well-

established, groundwater-dependent (phreatophytic) greasewood-sacaton plant community, which is a plant community that is very sensitive to relative changes in groundwater levels. In contrast, the areas of vegetated dunes along the axis of the fluvial plain west of the graben are much lower in relief and less vegetated.

- Groundwater levels have lowered as much as ~4.8 m (13.1 ft) between 1920 and 2006 in areas west of the LLFZ. Continued groundwater lowering in the SNORT study area may adversely affect the phreatophytic plant community that is currently stabilizing a large quantity of sand adjacent to and near the SNORT facility.
- Destabilization of the less vegetated and low-relief dunes west of the SNORT muzzle poses a hazard of sand transport from westerly winds and deposition across the track. Destabilization of the larger expanse of moderately vegetated and high-relief dunes within the fault zones poses a hazard of sand transport from westerly winds and deposition across Baker Access Road. Continued sand transport east of the Baker Access Road poses an additional hazard of the initiation of dust-raising events from sand abrasion across the silt-rich fluvial plain and playa surfaces in the area.
- Future studies of sand and dust hazards in the NAWS China Lake should include detailed measurements of dust emissions potential to produce a dust emissions inventory combined with monitoring of meteorological and eolian transport parameters in key dust-producing areas

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LIST OF ACRONYMS

ALFZ	Airport Lake Fault Zone
DP	Sand Transport Potential
DRI	Desert Research Institute
EC	Electrical Conductivity
ENSO	El Niño/Southern Oscillation
GBUAPCD	Great Basin Air Pollution Control District
GPS	Global Positioning System
ICDD	International Centre for Diffraction Data
I/I _c	Intensity Ratio
IRSL	Infrared Stimulated Luminescence
K-feldspar	Potassium feldspar
LLFZ	Little Lake fault zone
NAD	North American Datum
NAIP	National Agriculture Imagery Program
NAWCWD	Naval Air Warfare Center Weapons Division
NAWS	Naval Air Weapons Station
NOAA	National Climate Data Center
PDSI	Palmer Drought Severity Index
PRISM	Parameter Elevation Regression on Independent Slopes Model
RDP	Vector Sum Sand Transport Potential
SNORT	Supersonic Naval Ordnance Research Track
SOI	Southern Oscillation Index
SST	Sea Surface Temperature
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
VU	Vector Units
WT %	Weight %
XRD	X-ray diffraction

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1.0 INTRODUCTION

NAWS China Lake is situated in an arid, windy location, in which wind-blown sand and dust are significant surface processes that may affect the operations and long-term sustainability of the station. In addition, sand transport and dust emissions have the potential to produce negative impacts on Ranges and Airfield activities as well as create significant hazards to personnel, equipment, sensors, aircraft, and civil infrastructure.

Sand movement by wind, including migration of vegetation-free dunes and sand encroachment on infrastructure may impact the performance of critical facilities (e.g., SNORT; NAWS China Lake airfield) and thereby affect range operational sustainability. Further, wind-blown sand can bury important instrument sites (e.g., KTM positions), accumulate against boundary fences (fence-line dunes), and degrade fence performance as a secure barrier and negatively impact installation security. Sand encroachment onto roads and other facilities is a potential traffic hazard, can disrupt engineered surface drainage systems, and may incur costs related to removal or other mitigation measures.

Airborne dust has the potential to impact sensitive instrumentation, electronics and communications systems as well as to reduce visibility and impede flight operations. Dust storms are a significant and widely recognized geologic hazard in arid regions of the southwest U.S., including the Mojave Desert and adjacent areas. China Lake has experienced the impact of dust storms for many years. In the past, most of the effects were from dust emitted from the bed of Owens (Dry) Lake to the north, which resulted in restriction of flight operations at China Lake (Saint-Amand et al., 1986). Since dust control measures were initiated after 2000, this source of dust has largely been diminished, emphasizing the importance of local sources of dust, which may be enhanced by surface disturbance and/or lowered groundwater levels, and movement of sand by wind.

In this report, we document the results of studies of sand and dust hazards conducted in the vicinity of SNORT. The primary objective of these studies is to provide NAWCWD with the information needed to: (1) assess the eolian hazards to existing and planned facilities in the vicinity of SNORT and (2) develop sustainable long-term mitigation and control of sand encroachment and dust emissions to protect these facilities. In addition to the assessment of the area adjacent to the SNORT facility, we have begun to document and assess the extent and long-term disposition of eolian deposits downwind of SNORT.

1.1 APPROACH AND METHODOLOGY

Prior DRI geomorphic mapping has indicated the presence of active sand transport and vegetated sand sheets in the area of the northern SNORT alignment (Figure 1-1). Studies conducted in FY2016 build on this mapping through analysis of eolian landforms and available climate data. Analyses include detailed mapping of eolian landforms and documentation of landscape changes that have occurred over time, and historical analysis of relations between

observed changes and changes in climate, vegetation, land use, and hydrology. Although the focus is on the SNORT facility, the zone of eolian influence is much larger than the footprint of SNORT. The studies documented in this report extend beyond this facility in order to capture upwind and downwind areas and to assess the impact of potential future change in climate, natural changes in the geomorphic system, land use, or anthropogenic disturbance.

In studies conducted in FY2016, the primary objectives were to:

- 1) Identify existing areas of mobile sand and those that are potentially mobilizable
- 2) Determine the history of critical areas of actual or potential sand encroachment on infrastructure and facilities on decadal and longer timescales
- 3) Determine source(s) of sand that is encroaching on NAWS facilities
- 4) Assess cause(s) of sand encroachment in relation to climate, land-use change, change in hydrology, vegetation change
- 5) Provide recommendations for sand control measures that can be implemented to protect range sustainability and security

2.0 EOLIAN ENVIRONMENT OF CHINA LAKE

Site-specific studies of sand encroachment and dust emissions need to be placed within the context of the overall pattern of sand movement and dust events in the area of NAWS China Lake. This section provides information on the annual and seasonal pattern of wind speed and direction, which determines the sand transport (also sand drift) potential for the area. The wind regime also controls the magnitude and frequency of dust events. In this section, we provide information on the local and regional wind regime and assess its potential for sand transport and dust emission events.

2.1 WIND REGIME

The seasonal distribution of wind speed is related to the seasonal pattern of frontal systems, in which cyclogenesis and topographic effects of the Sierra Nevada and Tehachapi Mountains are maximized in late winter and early spring (Jewell and Nicoll, 2011). Northerly wind events are associated with the passage of cold fronts; while strong southerly wind events occur ahead of an upper level trough off the California coast (Shiyuan et al., 2008).

Observations of wind speed and direction at the China Lake airfield weather station have been made since 1946. We analyzed these data for the period from 1946 to 2013 using data downloaded from the California Climate Data Archive website (<http://www.calclim.dri.edu>) for NAWS China Lake ICAO station (KNID). Wind data comprised annual summaries of hourly averaged wind speed and direction classified into 16 directional sectors and 3 m/sec (6.71 mph) speed classes. Calm winds were designated as wind speeds less than 1.3 m/sec (2.91 mph).

Large gaps exist in the availability of wind data and most years have incomplete data sets. Wind data were available from the data archive for the period 1946-1949; 1970-1998; and 2001-2015. Data completeness, defined as the percentage of hourly observations compared to the total number of hours in a year ranged from 17 percent in the 1970s to 100 percent in 1949 with many years achieving a data completeness of 60-70 percent.

For example, the wind regime for China Lake basin are calm (< 1.3 m/sec; 2.91 mph) for 23 percent of the time for the period 2001-2013. The wind regime is dominated by winds from the south through west directions. This is also the sector from which the strongest winds blow. Winds from this sector account for approximately 41 to 68 percent of all winds over the year, with the maximum from this sector occurring in April.

2.2 SAND TRANSPORT POTENTIAL

Sand transport potential (DP) was based on observations of wind speed and direction at the China Lake airfield weather station during the period from 1946 to 2013. The sand-moving wind regime is defined in terms of the proportion of winds from different directions that have the potential to transport sand, because they exceed a threshold wind speed for sand movement. Once the wind speed exceeds the transport threshold, the rate of sand movement by wind increases exponentially. As a result strong winds have a much greater effect on the rate of movement compared to weaker winds.

Sand transport potential was calculated using the approach of Fryberger (1979) as modified by Bullard (1997) for use with wind speeds in meters per second. Despite some biases (Pearce and Walker, 2005), the method is well-accepted and has been used in many studies.

Sand transport potential is defined as:

$$DP = (V^2 (V - V_t)^2 * t) \quad (1)$$

where DP is the sand transport potential in arbitrary units, called 'Vector Units' (VU), V is the wind speed, V_t is the threshold wind speed for transport at the height of the wind recorder, and t is the percentage of the time the wind is blowing from a given direction. Values of DP are calculated for each wind speed class and direction and summed to estimate a total sand transport potential. A vector sum sand transport potential (RDP) was also calculated.

The threshold wind speed for transport was selected as 7 m/s (15.66 mph) at an anemometer height of 10 m (32.81 ft.). This is the threshold used by the Great Basin Air Pollution Control District (GBUAPCD) at the nearby Owens Lake basin and is based upon a correlation of wind speed records with actual measurements of sand movement.

It should be noted that the rates calculated from wind data are potential rates, and actual rates may be much less, depending on the availability of sand for transport.

2.2.1 Annual and Seasonal Patterns of Sand Transport Potential

Sand transport potential (DP) at NAWS China Lake is dominated by winds from the south through west sector, and this sector accounts for as much as 83 percent of annual potential sand movement (Figure 2-2). For the period 2001-2013, the annual sand transport potential (DP) varies between 26 and 57 Vector Units, classifying it as an intermediate energy wind regime following Bullard (1997).

There is a strong seasonal pattern to sand transport potential paralleling the seasonal variation in wind speed (Figure 2-3). Sand transport potential reaches a maximum in April and May, with as much as 51 percent of annual potential sand transport occurring in the period March - May. Rainfall amounts during the winter-spring period, growth of rainfall-dependent ephemeral vegetation, and surface soil moisture may reduce actual sand transport by some degree depending on the antecedent conditions.

The vector sum (resultant) direction of sand movement for the year is 45° or towards the northeast.

2.2.2 Inter-Annual Variability of Sand Transport Potential

Several studies have suggested that there are decadal-scale patterns in wind speed and direction in the Great Basin and adjacent areas, related to variations in the frequency and magnitude of mid-latitude cyclones that influence regional pressure gradients (e.g. Jewell and Nicoll, 2011, and references therein).

Data gaps make it difficult to assess decadal-scale patterns in sand transport potential at China Lake. The available data suggest that sand transport potential was high in the late 1940s, much lower (by a factor of 2-5 times) in the 1970s and 1980s, and decreased steadily to the early 1990s. Sand transport potential increased rapidly in the 1990s and remained relatively high thereafter (Figure 2-4). Although some of these changes may be the result of unknown differences in the location and height of anemometers, the overall pattern resembles that generated from a different wind data set for China Lake, using the same methodology as this study, by Jewell and Nicoll (2011). Their analysis indicates a high-energy wind regime in the 1950s, decreasing in a stepwise manner to intermediate to low energy in the period 1959-1986 and low energy from 1986 to 1995. As in this study, the Jewell and Nicoll data show a stepwise increase to a higher energy wind regime (similar to that of the 1950s) after 1997. These patterns in wind strength of regional extent and are believed to be the result of multi-year changes in atmospheric circulation patterns involving varying frequency of mid-latitude cyclones that have been verified by climate model simulations (Jewell and Nicoll, 2011).

2.3 DUST EVENTS

The magnitude and frequency of dust events is an index of rates of wind erosion in the immediate vicinity of a defined location. Reduction of visibility by blowing dust may also indicate an influx of dust from neighboring upwind sources. Dust storms are defined as severe weather conditions in which visibility is reduced to 1 km or less by windblown dust suspended in the air.

The frequency of dust storms is measured by the number of such events in a given time period. The magnitude of dust storms can be assessed by the duration of such conditions. Dust events (also known as dust haze) are conditions when visibility is reduced to 11.3 km (7 mi) or less by dust suspended in the air. Blowing dust is defined as a condition when dust is raised to a height of 2 m (6.5 ft) or more by strong winds, but does not reduce visibility to less than 1 km (0.6 mi).

First order meteorological stations such as at China Lake may record these conditions as part of their normal schedule of hourly observations. Such data have been used to assess the frequency of dust storms in relation to climatic parameters, such as annual and seasonal precipitation (e.g. Bach et al., 1996; Brazel, 1989; Middleton et al., 1986). Following procedures in Bach et al. (1996), the number of occurrences of dust storms and dust events was extracted using the VSB (Visibility) and MW (weather type) fields from the hourly observations at China Lake airfield contained in the surface hourly abbreviated format data set provided by the NOAA National Climate Data Center. Data were available for the period 1946-2015.

True dust storms, as defined above, appear to be rare at China Lake. No occurrences were recorded in the available data set. The lowest visibility observed was 1.6 km (1 mi) at 11:00 a.m. on January 1, 1946, associated with a 20.6 m/s (46 mph) wind from the north. Dust events (visibility <11.3 km; 7 mi) occur in most years of the record at a variable frequency (Figure 2-5). The maximum frequency of dust events observed was in 1955 with 77. Other peaks in the number of dust events occurred in 1971, 1975, 1985, 2011, and 2014. No dust events were recorded for the period 1994-2000. It is not clear if this represents a gap in the record, or corresponds to a real minima in occurrence. Analysis of the data indicates that there may have been an overall decline in the frequency of dust events over the period of record (Figure 2-5).

On a seasonal basis, the maximum frequency of dust events occurs between February and May with 50 percent of the recorded dust events occurring in February and March (Figure 2-6). The lowest frequency of dust events occurs in the summer and fall months (July –October); however, the peak in dust events precedes the local maximum in sand transport potential between April and May). In contrast to the dominance of sand transport potential by south to southwest winds, most dust events are associated with winds from the north to northwest. In addition, the annual frequency of dust events is broadly anti-correlated with antecedent precipitation (Figure 2-7), thereby indicating that periods of lower precipitation tend to be associated with increased dust event frequency.

3.0 TECTONIC AND HYDROGEOMORPHIC SETTING OF THE STUDY AREA

3.1 TECTONIC SETTING

The SNORT study area is located within the southwestern sector of the North Range of NAWS China Lake, and encompasses the northern half of the 6.55-km (4.07-mi) long track alignment (Figure 3-1). Based on repeat, high-resolution leveling surveys of the SNORT track between 1952 and 1986 and published studies of active tectonics and volcanism in the area, Zellmer and Roquemore (1997) concluded that the SNORT area is actively being deformed by coupled movement from the Little Lake fault zone (LLFZ) and Airport Lake fault zone (ALFZ), and an underlying shallow (~3-km deep) magma body. The LLFZ is the principal fault system that crosses Indian Wells Valley and is characterized as an oblique, right-lateral (i.e., horizontal) fault with down-to-the-east normal (i.e., vertical) displacement, whereas the ALFZ is an oblique, right-lateral fault with down-to-the-west normal displacement that bifurcates from LLFZ in the north-central part of the valley (Roquemore and Zellmer, 1987) (Figure 3-1). Both fault zones are expressed at the surface as a distributed zone of short, en echelon scarps that have experienced two historical ground-rupturing earthquakes, the first in 1982 and the second in 1995 (Figure 3-1). Although the surface rupture traces were relatively short (~2 to 3 km; ~1.2 to 1.9 mi), they were associated with earthquakes of ML 4.9 and 5.4, respectively (Hauksson et al., 1995).

The style and magnitude of recent surface deformation of the SNORT alignment reflect complex fault geometry between the LLFZ and ALFZ. The intersection of the LLFZ and ALFZ occurs about 2.1 km (1.3 mi) east of SNORT within the Sand Transport study area (Figure 3-2). Here, the LLFZ exhibits a large left-step and forms a localized graben (i.e., pull-apart basin) that distributes strain in a northwest-southeast direction, whereas the ALFZ bifurcates to the north and transfers strain along the eastern margin of the graben (Figure 3-2). The dominant style of coseismic deformation within the left-step during surface rupturing events is permanent surface subsidence, whereas interseismic deformation is reflected by cyclic strain accumulation (Zellmer and Roquemore, 1997). The location of the fault zones and related geometry forms a structural and topographic low that controls local groundwater conditions and drainage patterns, which in turn, influences the distribution and magnitude of stream (i.e., fluvial) and sand (i.e., eolian) deposition in the area (Figure 3-2).

3.2 GEOMORPHIC SETTING

The SNORT study area contains a variety of landforms and deposits (Figure 3-2), reflecting its location between alluvial fans extending from the Sierra Nevada to the west and southwest and the central playa area of China Lake to the east. Table 3-1 shows the proportions of landforms and different deposits encountered in the study area, based on existing geomorphic mapping (Bacon et al., 2015), which was revised for this study.

3.2.1 Alluvial Landforms

Low gradient distal alluvial fans of latest Pleistocene to recent age cover about 13.6 percent of the study area in its northwestern and southwestern corners. The northern (~1.9 km; 1.2 mi) of the SNORT alignment crosses the well-developed and broad axial channel system of the Indian Wells valley watershed, which terminates in the China Lake playa. The channel system comprises fluvial plains extending eastwards from the distal alluvial fans and cover as much as 34.6 percent of the total study area. They consist of broad, low-gradient plains with areas of young playa and playette landforms. Fluvial plain areas are comprised of fine sand and silt, deposited by ephemeral flows emanating from areas of alluvial fans to the west and southwest of the study area along the axial channel system. Shallow active channels are locally incised into this unit. In the southern part of the study area, these units merge with an extensive area of dissected silty-clay playa deposits.

3.2.2 Eolian Deposits and Landforms

Eolian deposits cover about 41.6 percent of the study area, mainly in its eastern two-thirds and overlie the alluvial and playa deposits. Most of the eolian deposits are comprised of vegetated sand sheets, which are the most widespread landforms in the study area. Vegetated dunes cover about 10 percent of the study area, and are concentrated in the eastern part of the study area.

3.2.3 Dunes and Sand Sheets

The dunes have accumulated in two discrete areas that coincide with (1) the graben of the LLFZ and ALFZ, and (2) the axis of the broad fluvial plain west of the graben and SNORT (Figure 3-2). The vegetated dunes within the graben exhibit relief of up to ~8 m (26 ft) and are covered by a well-established, groundwater-dependent (phreatophytic) greasewood-sacaton plant community, which is a plant community that is very sensitive to relative changes in groundwater levels (e.g., Elmore et al., 2003). In contrast, the area of vegetated dunes along the axis of the fluvial plain west of the graben is much lower in relief and less vegetated.

All of the dune areas are partially to completely vegetated. Active (bare, mobile) sand was observed in several localities, most prominently on the head of parabolic dunes adjacent to the KTM 1001 study site (see Figure 3-2), and locally on linear dune ridges to the south and east of this area. The large parabolic dunes to the NE and all the dunes west of SNORT are effectively stabilized by vegetation and exhibit very low or negligible areas characterized by active sand transport.

The existence of parabolic dunes throughout the study area indicates that vegetation was present when they formed, as this dune type only forms in the presence of vegetation (Pye and Tsoar, 1990). Generally, the dunes have a lobate form (length/width ratio 1-3), indicating a relatively low rate of downwind migration. In addition to the dunes, a broad expanse of up to ~1 m (3.3 ft) thick sand sheets have accumulated local to the fault zones and the high-relief vegetated dunes east of SNORT (Figure 3-2).

3.2.4 Relationships Between Eolian and Other Geomorphic Units

Generally, dunes in the study area lie to the east of areas of fluvial deposition and active channels. The dunes also act as barriers to fluvial activity. For example, active slightly incised channels are diverted around the northern end of the KTM 1001 study site dune ridge complex. To the north of this area, active channels terminate between the arms of parabolic dunes (Figure 3-2).

3.3 HYDROGEOLOGIC SETTING

All available data from groundwater monitoring wells in Indian Wells Valley for the years 1920, 1985, and 2006 were used to estimate groundwater conditions in the SNORT study area. Surfaces of the groundwater table were constructed by interpolating observed water levels at 10-m (32.8-ft) resolution with a kriging routine in ArcGIS. Of precautionary note, some modeling artifacts exist within the southwestern corner of the square-shaped interpolated surface outside of the boundary of NAWS China Lake. This is a result of limited well data biased toward high groundwater levels; therefore, caution should be made when interpreting groundwater levels in this area. Maps of groundwater levels in relation to the southwestern sector of NAWS China Lake were prepared to evaluate the overall position of groundwater levels and rate of change in relation to active faults in the valley, as well as the configuration of water levels during early and recent groundwater development (Figures 3-3 to 3-8).

3.3.1 Groundwater Levels

In general, the configuration of shallow groundwater levels in 1920 closely coincides with the southern section of LLFZ and to the left-stepping and branching sections of the LLFZ and ALFZ in the north (Figure 3-3). In contrast, a well-developed cone of depression related to groundwater development controls the overall configuration of groundwater levels outside and bordering the southwestern corner of NAWS China Lake by 1985 and 2006. Groundwater level changes within this cone of depression range as much as -24 m (-78.7 ft) between 1920 and 1985 to relatively lesser values of -9 to -10 m (-29.5 to -32.8 ft) between 1985 and 2006 (Figures 3-4 and 3-5, respectively). The net groundwater lowering within the cone of depression during the period of record from 1920 to 2006 is about -32.3 m (-106 ft) (Figure 3-6).

3.3.2 Rate of Change in Groundwater Levels

The spatial-temporal change of shallow groundwater levels during the periods 1920–1985 and 1985–2006 also reflect the expansion of groundwater development. Between 1920 and 1985 the rate of change of groundwater lowering was as much as -0.37 m/yr (-1.2 ft/yr) and focused outside and adjacent to the south-southwestern boundary of NAWS China Lake (Figure 3-7). Between 1985 and 2006 the rate of change of groundwater lowering increased to as much as -0.48 m/yr

(-1.6 ft/yr), which was principally focused along a ~5-km (3.1-mi) long and ~2-km (1.2-mi) wide band encompassing the southwestern corner of the NAWS China Lake boundary (Figure 3-8). The groundwater surface along the northeastern margins of the cone depression appears to terminate near the LLFZ. As a result, it is likely that the LLFZ controls the configuration of the cone of depression, as well as localized areas of the groundwater table adjacent to the entire length of the LLFZ. This is illustrated along the -9 to -12 m (-29.5 to -39.4 ft) contour in Figure 3-6 and the change in groundwater level maps on Figures 3-7 and 3-8.

3.3.3 Hydrogeomorphic Profiles

The interpolated groundwater levels in the SNORT study area for the years 1920 and 2006 were projected onto two geologic cross sections oriented longitudinal (A–A') and transverse (B–B') to the broad fluvial plain to aid in understanding the geomorphology in the area in relation to shallow groundwater conditions and active faulting (Figures 3-9 and 3-10). The subsurface geology shown on the cross sections is based on observed stratigraphic exposures at the KTM 1001 trench site (see Section 4.0), descriptions from a nearby ~10.7-m (35.1-ft) deep sediment core (Core 9 of Meyer et al., 2011), inferences from mapped geomorphology, and location of faults modified after USGS (2016). In addition, the location of groundwater monitoring wells and their observed changes in water level and rates of water-level change over different periods is plotted on the geomorphic and fault map of the SNORT study area (Figure 3-9). Of note, there are two discrete sets of rates of water-level change that appear to reflect monitoring well distance from the LLFZ independent of any influence from the north-northeastern expansion of the cone of depression to the south (e.g., Figure 3-6).

Three monitoring wells within 200 m (660 ft) of the mapped surface trace or inferred location of the LLFZ exhibit relatively lower rates ranging from -0.03 to 0.02 m/yr (-0.08 to 0.06 ft/yr), whereas wells located 440 m (0.27 mi) to 2.1 km (1.3 mi) away from the LLFZ have relatively higher rates ranging from -0.13 to -0.05 m/yr (-0.42 to -0.16 ft/yr) (Figure 3-9). The interpolated positions of the groundwater table in 1920 and 2006 shown on the cross sections (Figure 3-10) also show this relation. The long-term change in water level and rate of change is much greater west of the fault zones and significantly lower proximal to and within the fault zones where groundwater levels appear to have changed little over the 86-year period of record (Figure 3-10). Furthermore, the presence of the large area of well-developed vegetated dunes coincides with a subtle bulge and the shallowest groundwater levels across the fault zones.

4.0 EOLIAN STRATIGRAPHY AND CHRONOLOGY

Stratigraphic studies were conducted in the SNORT study area to provide a long-term context for the studies of recent eolian history, as well as to provide information on the conditions in which past episodes of eolian activity involving dune formation and/or reworking occurred. In this study, “long-term” means periods prior to the designation of China Lake as a DOD facility, i.e. prior to the 1940s.

4.1 KTM 1001 STUDY SITE

A subsurface investigation of eolian deposits at the KTM 1001 study site was performed in February of 2016. This investigation included the evaluation of a preexisting, ~10-m (32.8-ft) deep trench excavated through a prominent dune ridge and into older fluvial and lacustrine to deltaic deposits east of SNORT and adjacent to KTM 1001 (Figure 3-2). Sediment exposed in the KTM 1001 trench were described and sampled for particle size, geochemical analyses, and infrared stimulated luminescence (IRSL)-age dating, and were surveyed using a combination of auto-correction global positioning system (GPS) and total-station for location and elevation control. A ~2.5-m (8.2-ft) deep, hand-auger borehole was also placed at the bottom of the trench to explore deeper stratigraphy and sample for IRSL dating.

The KTM 1001 trench was previously excavated to approximately 4 m (12 ft) below local ground surface at around 669 m (2195 ft) elevation and through a 5-m (16.4-ft) high dune, thereby offering an opportunity to characterize past episodes of eolian sand accumulation and pre-eolian depositional environments (Figure 4-11).

4.1.1 Trench Stratigraphy

The sedimentology, stratigraphy, and soil-geomorphology of deposits exposed in trench walls were studied at three locations (Figures 4-2 and 4-3). Full details of the sediment and soil descriptions are provided in Appendix 4A. Samples for IRSL dating were acquired from upper and lower stratigraphic levels within eolian deposits exposed in trench walls.

The upper dune stratigraphy at the trench site was described at the KTM West locality at elevations between 669 and 674 m (2195 and 2211 ft) (Figures 4-2 and 4-3). Here, sediment consists of 5-m (16-ft) of very pale brown fine to medium eolian sand (Figure 4-4). The sands are dominantly massive, with finely disseminated calcium carbonate and weak sub-planar laminae and cross stratification at some levels. See profile descriptions of sites CL-16-1 to CL-16-6 for details (Appendix 4A).

The lower dune stratigraphy was described at the KTM East (North) locality at an elevation between 665 and 667 m (2182 and 2188 ft) (Figures 4-2 and 4-3). The sediment exposed here includes up to 2 m (6.6 ft) of massive fine to medium eolian silty sand that overly a buried soil

developed on ~1-m (3-ft) thick sandy silt to silty clay interpreted to be a flood plain (playa) deposit. The lower contact of the flood plain deposit represents an erosional boundary that formed on relatively older, massive to thinly interbedded, silty clay lacustrine to sandy silt deltaic deposits associated with ancient water levels of China Lake (Figure 4-3). Stage 1 to 1+ carbonate development occurs in eolian deposits. Sub-planar stratification and weak cross bedding occurs in the eolian sand deposits (Figure 4-5). Based on the topographic and stratigraphic position of the KTM East (North) exposure, these sandy sediments are likely the oldest eolian deposits at the KTM 1001 study site. See profile descriptions of sites CL-16-7 and CL-16-8 for details (Appendix 4A).

An additional site of lower dune stratigraphy was described at the KTM East (South) locality at an elevation near 668 m (2192 ft) (Figures 4-2 and 4-3). About 1 m (3 ft) of massive poorly sorted medium eolian sand with weak development of sub-planar stratification is exposed at this location (Figure 4-6). The upper 0.3 m (1 ft) of the exposure exhibits bioturbation and prominent roots down to a depth of 0.55 m (1.8 ft). See profile descriptions of site CL-16-9 for details (Appendix 4A).

4.1.2 Detailed Analysis of Upper Dune Stratigraphy

A detailed sedimentologic analysis of upper dune deposits at the KTM East (North) locality was performed to identify subtle depositional contacts within the massive exposure of sand (Figure 4-7). Four sedimentary subunits at this location were distinguished based on mean grain size and sorting, as well as silt and clay and carbonate contents. From top to bottom (youngest to oldest) of the section they are:

- Unit 1:** 0 – 2 m (0-6.6') depth; moderately sorted medium sand
(mean grain size 248-291 μm), 5-6% silt and clay and carbonate.
- Unit 2:** 2 – 4 m (6.6-13') depth; moderately well sorted fine sand
(mean grain size 140-175 μm), 9-11% silt and clay, 7-8% carbonate.
- Unit 3:** 4 – 4.5 m (13-15') depth; moderately sorted fine sand
(mean grain size 190 μm), 9% silt and clay; 7% carbonate content.
- Unit 4:** > 4.5 m (15') depth; moderately well sorted fine sand
(mean grain size 184 μm), 5 – 6% silt and clay and carbonate content.

4.2 CHRONOLOGY OF EOLIAN DEPOSITS

4.2.1 Luminescence Analysis

Infrared stimulated luminescence (IRSL) analysis was used to directly date eolian and lacustrine to fluvial-deltaic sediment at the KTM 1001 study site (Figure 4-3). Nine samples were collected in tubes tapped into eolian sand dune deposits exposed in the walls of the KTM 1001 trench (CL-16-1 to CL-16-9), whereas one sample was collected from a borehole hand augured into lacustrine to fluvial-deltaic deposits at the floor of the trench (CL-16-10). In situ sampling in tubes ensured no light exposure, and samples were prepared and analyzed at the Desert Research Institute Luminescence Laboratory (DRILL). Typical methods were used to isolate coarse grained

(220-300 μ m) potassium feldspar by removing carbonates, organics, and magnetic sub-fractions, and mineral separation with lithium heterotungstate. The feldspar portion of the sample was etched in hydrofluoric acid to remove the outer layer of the grains that is affected by irradiation from α particles, and the sample separate was then re-sieved to remove any grains that were reduced to < 220 μ m by etching. Luminescence ages are expressed as thousands of years before 2018 and rounded to the nearest 10 years (Table 4-1).

4.2.1.1 Luminescence Results

In general, the IRSL ages match very well with the described dune stratigraphy and soils, and all ages are in stratigraphic order. The stratigraphy and supporting ages indicate two distinct periods of sand accumulation at the site consisting of an earlier period at 2.0–2.14 ka and a later period at 0.92–1.22 ka. The entire package of late Holocene eolian deposits are underlain by flood plain deposits with a buried soil. These flood plain deposits are in turn underlain by lacustrine to fluvio-deltaic deposits that yielded an IRSL age of ~21 ka from the borehole (Table 4-1; Figure 4-3). The late Pleistocene age coincides with the last glacial maximum in the Sierra Nevada and the highstand of a large and deep pluvial China/Searles Lake. The IRSL ages provide information to quantify the timing and duration of periods of eolian accumulation and will enable correlation of these periods with other records of eolian accumulation in the region, as well as with paleoclimate proxy data. This will provide information to assess the paleoclimatic and hydrologic conditions of the area in which the dunes were formed and/or reworked.

5.0 FIELD SAMPLING STRATEGY

To determine the source(s) of sand that is encroaching on SNORT, we have: (i) collected samples from recent sand deposits and potential sources of sand onsite at the NAWCWS China Lake, as well as offsite, for particle size and mineralogical analysis; (ii) conducted analyses of sand samples at DRI's Soil Characterization Laboratory for particle size composition, carbonate content, and salinity; and (iii) determined sand mineralogy using bulk X-ray diffraction. The resulting data set enables assessment of current and past sand source(s) and transport pathways.

Prior studies in similar desert environments (e.g. Lancaster et al., 2015; Muhs et al., 2003; Wasklewicz and Meek, 1995) have shown that comparison of sand mineral composition from deposits such as dunes and sand sheets with potential sources such as sand-sized material in alluvial deposits or ephemeral washes can constrain the source(s) of wind-blown sand.

Surface samples of sand were obtained along a west to east transect from the alluvial fans that emanate from the Sierra Nevada to the sand sheets east of the main China Lake playa adjacent to the Argus Range. In addition, sand samples from sub-surface dune stratigraphic units exposed in the trench at the KTM 1001 site east of SNORT were analyzed to assess possible changes in sand sources through time. Sample locations are shown on Figure 5-1 and detailed coordinates are given in Table 5-1.

Following clearance by a UXO technician, surface samples were collected by scraping an area of approximately 0.09 m² (1 square foot) and 2 cm (1 inch) in depth into a plastic sample bag,

yielding a sample of approximately 500 gm (1 lb). Subsurface samples from the KTM 1001 trench site (see section 4) were approximately 500 gm (1 lb) and were obtained from the exposed face of excavations made for stratigraphic description and IRSI sampling (see Figure 4-4), at the same point as the IRSI dating sample. Field sampling resulted in a total of 20 samples for determination of particle size and composition.

5.1 SEDIMENTOLOGICAL CHARACTERIZATION

The particle size and sorting characteristics of sands and their spatial distribution, such as fining and increased sorting in the direction of transport, can provide information on potential sources and transport pathways. Similarly, the mineralogy of sand and secondary accumulations of salts and carbonates can reveal important information regarding sediment sources, weathering characteristics, transport distances, and relative ages of deposits.

5.1.1 PARTICLE SIZE CHARACTERIZATION

5.1.1.1 Particle Size Analysis

Particle size was analyzed using a combination of sieving and laser diffraction methods on the fine earth fraction ($<2\text{mm}$) to determine the percentage of sand, silt, and clay in each sediment sample. Samples were initially processed to determine moisture content and percent gravel by drying and sieving to obtain the 2mm particle-size fraction. Samples containing >2 percent organic material were pretreated with 30 percent hydrogen peroxide for removal of organic matter. Samples containing >2 percent calcium carbonate were pretreated with a buffered glacial acetic acid solution for calcium carbonate removal. Samples were split and externally dispersed in a surfactant solution (0.02g/L sodium metaphosphate) on a mechanical shaker for 12 hours, then wet sieved to $63\mu\text{m}$. A subsample of the fine fraction ($<63\mu\text{m}$) was analyzed on a laser diffraction particle size analyzer (Saturn Digisizer 5200) and the coarse fraction ($>63\mu\text{m}$) was collected/dried and sieved using a stack of nested 3-inch diameter sieves. Laser conditions for the Digisizer included a flow rate of 11 liters/minute, 90 seconds of ultra-sonication and 6 repetitions at 35 percent laser obscuration. Grain size and sorting measures were calculated using GRADISTAT (Blott and Pye, 2001), using the method of moments.

5.1.1.2 Particle Size Analysis Results

The texture of surface sand in the China Lake study area consist of fine- to coarse-grained sand (Table 5-2), which varies from west to east (Figure 5-2), but is dominated by medium and fine sand (0.5- 0.125 mm). Very coarse and coarse sand dominate at the Kennedy Stands dune areas and coarse sand is common in eolian deposits along the western boundary fence and in the distal alluvial sediments of Short Canyon wash.

All surface sands contain more than 2 percent silt and clay size material ($< 63 \mu\text{m}$), with a maximum of 7.8 percent. Subsurface sands from the KTM 1001 trench (CL-16-1 to CL-16-9) are enriched in silt and clay size material (mean 8%), as are sands from the vicinity of SNORT (CL-16-16 and CL-16-17) (6.5 – 7.6%). These values are similar to those reported from Owens Lake dunes by Lancaster et al., (2015), where silt and clay percentages range between 2.6 and 9.82 weight %

(mean 4.58%). In comparison, (Sweeney et al., 2016) report silt and clay percentages of 1.4 to 3.2 percent from vegetated dunes in China. Similarly, surface sand from vegetated dunes in the Kalahari contains less than 2 percent (mean 0.50%) silt and clay (Bhattachan et al., 2013).

Table 5-3 summarizes the particle size and sorting statistics. Mean grain size of sand from the studied area ranges between 100 and 293 μm (1.85 – 2.93 phi); sorting (sigma) varies between 0.55 and 1.09, or moderately-well to poorly sorted, with the majority of sands being moderately sorted. All surface sands sampled are strongly fine skewed with a tail of fine particles (i.e. they have positive skewness values). As shown in Figure 5-3, mean grain size and sorting are strongly correlated, indicating that finer sand fractions are better sorted than coarser sands.

Laser particle size analysis conducted on three samples from stabilized dunes at the KTM 1001 trench site to determine the particle size distribution of the fine ($<63\mu\text{m}$) fraction showed that the particle size distribution of all three samples was similar (Figure 5-4). There are two distinct peaks: a broad coarse silt peak (50-20 μm) and a strong peak at 2 – 0.5 μm .

5.1.1.3 Particle Size Analysis Summary

Eolian deposits from the China Lake study area consist of moderately- to poorly-sorted medium to fine sand. They are generally less well-sorted and coarser than typical eolian dunes. Sand characteristics from the China Lake basin are comparable to sand from dunes and sand sheets in the Owens Lake basin (Lancaster et al., 2015), as shown in Figures 5-5 . In general, sands from these adjacent basins are very similar in mean grain size and sorting, with the China Lake sands being slightly finer in mean grain size.

5.1.2 Calcium Carbonate and Salinity Characterization

5.1.2.1 Calcium Carbonate and Salinity Analyses

The analysis of calcium carbonate and soil salinity followed standard procedures for analyzing soils (Soil Survey Staff, 1998). Calcium carbonate content (wt %) was determined using a pressure calcimeter method (Sherrod et al., 2002) on a subsample of crushed material. Salinity was estimated from electrical conductivity (EC) of an aqueous soil extract using a standard conductivity meter (Rhoades, 1996).

5.1.2.2 Calcium Carbonate and Salinity Results and Summary

Samples of surface sands contain between 0.3 and 5.5 percent calcium carbonate, with the majority containing less than 2 percent CaCO_3 (Table 5-2). Surface sands from the SNORT area have a higher calcium carbonate content (2 – 5.5%) than elsewhere in the China Lake study area. Subsurface sands from the KTM 1001 trench have a generally higher calcium carbonate content (mean 6.7%). With one exception (Short Canyon wash), calcium carbonate content and silt and clay content are closely correlated. All sands are classified as non-saline (Table 5-2). Higher salinities are associated with stabilized dunes and increase sharply with depth at the KTM 1001 trench site.

5.1.3 Bulk X-Ray Diffraction (XRD) Characterization

5.1.3.1 Bulk X-Ray Diffraction (XRD) Analysis

The 20 sediment samples from China Lake were prepared for bulk XRD analysis by splitting out ~6g of the oven dried <2mm fraction of the sample and grinding it by hand with a mortar and pestle until it passed through a sieve with openings of 500µm. Samples were then ground to a powder in a McCrone mill for 8 minutes in 10 ml of methanol. Samples were then air dried overnight, gently re-crushed in a mortar and pestle to break up aggregates formed during drying, and side-loaded into specially-designed side-loading sample holders. This process of grinding the samples to a fine homogenous powder, followed by side-loading, helps to reduce preferred orientation of certain crystal phases within the samples, which is important for semi-quantitative analysis; however, a certain amount of preferred orientation still tends to occur. The resulting XRD scans were viewed and interpreted using the Bruker XRD data evaluation software called EVA. A background correction, a K-alpha2 stripping operation (0.5 ratio), and x-offset correction were performed on each scan before interpretation. Minerals were identified by matching reference mineral patterns stored in the ICDD (International Centre for Diffraction Data) database to the observed peaks.

The method used to estimate the relative percentages of each mineral identified (i.e., the semi-quantitative analysis) is based on the method of Chung (1975), which assumes that all the minerals are identified correctly and that there are no unidentified phases in the sample. It is carried out within EVA by adjusting the y-scale of the reference patterns (visually represented by sticks in the plots) to match the peak heights on the observed scan. A reference intensity ratio (I/I_c) for each mineral is then used to determine the relative percentages. In this case, I/I_c is the relative height of the strongest peak of a mineral compared to the relative height of the strongest peak of corundum in a 1:1 mixture. The calculation is done automatically by the software once each mineral selected is assigned an I/I_c value. The I/I_c values for most of the mineral reference patterns used were provided by the ICDD database. Otherwise values were taken from Davis et al. (1989). Because generic I/I_c values were used (the same basic mineral type can have a range of I/I_c values), the relative percentages of the mineral determined can be assumed only to be semi-quantitative estimates rather than quantitative values (no estimation of uncertainty can be provided). Although the accuracy of the percentages cannot be tested, because the same minerals were identified in all samples in the batch and the same reference patterns and I/I_c values were used throughout, the percentages are useful for comparing samples within the batch.

5.1.3.2 Bulk X-Ray Diffraction (XRD) Results

The bulk mineralogy of sand samples determined by the semi-quantitative XRD analysis is provided in Table 5-4. XRD scans (see Appendix 5A and 5A-1) are similar for all samples and indicate that quartz and plagioclase are the two major minerals (present at concentrations >~20%). Results indicate that quartz and plagioclase combine to comprise ~75-90 percent of the identified mineral content. Potassium feldspar (K-feldspar) appears to be the third most concentrated mineral in all samples, occurring in minor amounts (~5-20% of the identified mineral content). The scans indicate that calcite is present in minor (~5-20%) in 12 of the 20 samples and in trace (<~5%) amounts in 5 samples, while it is below detection limit in 3 samples. Results also suggest that amphibole (a silicate mineral generally containing iron and/or magnesium) is present in trace

amounts in 12 or 15 samples. The absence of amphibole peaks in the other scans may be a result of the fact that XRD methods cannot reliably detect components present at <5 percent.

5.1.3.3 Bulk X-Ray Diffraction (XRD) Summary

The sand from the China Lake study area contains a high percentage (>50%) of plagioclase and K-feldspar minerals suggesting the sand has not been exposed to significant chemical weathering from soil-forming processes. Sand containing high amounts of these granitic materials typically can be characterized as mineralogically very immature (Muhs, 2004). The sand at the China Lake study area may be enhanced in K-feldspar compared to most sand at Owens Lake (Lancaster et al., 2015) (Figure 5-7), but it is similar to sand from most areas of the Mojave Desert (Muhs et al., 2003) where there is an abundance of source areas composed of granite and granodiorite.

The relative proportions of quartz, plagioclase, and K-feldspar in the sand from the China Lake study area are a good indicator that they are derived from a local granodiorite source rock, which is the predominant igneous-intrusive rock type in the nearby Sierra Nevada and forming the core of the Coso Range (Hollett et al., 1991). The high percentage of a granitic mineral assemblage in the sand is consistent with very short transport distances from source to deposition site and a relatively short residence time in the fluvial and eolian depositional environments.

5.2 SPATIAL VARIATIONS IN SEDIMENT CHARACTERISTICS

The spatial distribution in particle size, sorting, and chemistry varies from west to east across the sampling transect (Figure 5-6), with the west end of the sampling transect situated at the base of the range-front of the Sierra Nevada. Mean grain size decreases and sorting improves eastward from the Sierra Nevada piedmont to the SNORT area. The Kennedy Stand dunes are significantly coarser and less sorted than other areas. Carbonate and silt and clay content are much higher in the SNORT area, compared to areas west and east of this location. The particle-size characteristics indicate that wind-blown sand becomes finer from west to east, from the range front to the SNORT area. East of SNORT at the Kennedy Stand dunes, sand is coarser and less well sorted, and becomes finer grained to the east. Sands from the vicinity of SNORT are significantly enriched in carbonate, silt, and clay, compared to areas upwind and downwind. These trends suggest that sand is not transported from west to east in a progressive manner, which would result in a monotonic decrease in particle size and an increase in sorting across the basin, but that there are at least two sources of sand in the study area: (1) washes directly from the Sierra Nevada watersheds, which supply sand to areas such as SNORT; and (2) the fluvio-deltaic sediments of the former Owens River fan-delta (Bacon et al., 2015) which supply areas such as the Kennedy Stand dunes. Given the high feldspar content of all sands in the China Lake study area, it is unlikely that the elevated silt and clay content is the result of weathering of feldspars. The correlation between silt, clay, and carbonate content suggests that the fine material is carbonate-rich dust derived from distal alluvial, lacustrine, or playa deposits in the vicinity of SNORT, which has accumulated over time in the vegetation-stabilized dunes.

6.0 RECENT HISTORY OF EOLIAN DEPOSITS AND LANDFORMS

In this section, we describe and discuss changes in the distribution of eolian deposition in the form of dunes and sand sheets in the vicinity of SNORT since the 1940s. Our analysis is based upon evaluation of aerial photographs and digital imagery acquired at four intervals beginning in 1948. Dune extent was mapped from imagery and changes in morphology, position and areal extent from year to year were assessed. The changes were compared to climatic proxy data and hydrogeologic information to evaluate the potential causes of observed changes in dune morphology, activity (amount of erosion and deposition combined), and extent.

6.1 APPROACH AND METHODS

The area of NAWS China Lake has been imaged by numerous aerial surveys since 1948. Dune extent was mapped on imagery acquired in 1948, 1971, 1984, 2004, and 2014 (Table 6-1) within an area of 22 sq. km (8.44 sq. miles) encompassing the northern half of the SNORT alignment and centered on the muzzle. The selection of imagery dates was governed in part by the availability of products with sufficient quality and resolution, and by the need to provide an assessment of dune extent and state (erosion, deposition, no change) over a relatively broad period of record.

Aerial photographs were georeferenced to known landmarks (e.g. road intersections) and converted to raster data with a 0.5 m x 0.5 m (1.6 ft x 1.6 ft) cell size in an ESRI ArcGIS platform. Dune extent was mapped as polygons for prominent and clearly identifiable dune features in the map area for each year. Dune features were identified based on their morphology, vegetation cover, and contrast with respect to surrounding playa and fluvial plain landforms and surficial deposits. The resulting polygons were then converted to individual raster data with a 10 m x 10 m (32.8 ft x 32.8 ft) cell size to quantify geospatial changes in the dune landscape in terms of annual rates of erosion, deposition, and no change during the different time intervals.

6.2 DUNE MAPPING

The dune mapping shows that the overall distribution and pattern of dune features on the 1948, 1971, 1984, 2004, and 2014 imagery has remained relatively similar over the 66-year period of record (Figure 6-1). Detailed geospatial analysis between the different years indicates that there have been small-scale changes at the edges of dune boundaries over the period of record.

6.2.1 Distribution of Dune Features

There are four principal areas of dunes in the vicinity of the northern SNORT alignment that have retained their general configuration over the period of available imagery. Each area is

partially to completely vegetated with a well-established cover of groundwater-dependent greasewood-sacaton plant community (Elmore et al., 2003). The four areas are:

- A. On the far western edge of the evaluated area is an area of irregular parabolic dunes (a1) and low sinuous vegetated dune ridges (a2) aligned perpendicular to westerly winds (Figure 6-1);
- B. West of the northern end of the SNORT alignment are irregular low sinuous ridges (b1) and low parabolic dunes (b2), with the “head” to the east and “wings” extending up to 300 m (984 ft.) to the west (Figure 6-1);
- C. In the northeastern sector of the evaluated area lie a series of small (1-3 m (3-10 ft) - high) parabolic dunes (c1) with wings as much as 100 m long. Two larger (3-5 m (10-16 ft.) high lobate parabolic dunes located farther east (c2) have developed by coalescence of several smaller dunes. Additional parabolic dune ridges occur east of Baker Access Road (Figure 6-1, c3);
- D. In the southeastern sector of the evaluated area there is a major N-S oriented dune ridge (d1) that rises up to 6 m (20 ft.) above the surrounding area. This dune ridge has been breached in the vicinity of the KTM 1001 site, and resulted in the development of a series of nested elongated parabolic ridges (d2) that extend eastward up to 400 m (1300 ft.). East of this dune ridge there are a series of small (2-3 m (7-10 ft.) high and 100-300 m (328-984 ft.) long) linear dune ridges (d3), spaced about 50 m (164 ft.) apart, and on a NW-SE trend. Similar but shorter and discontinuous ridges of sand <100–200 m (328-656 ft-) long occur to the west and south of these dunes, also on a NW-SE trend (d4). Dunes in areas C and D lie adjacent to and east of the Little Lake fault zone (see Figure 3-2).

The total dune area has varied between 1.09 million sq. meters (270 acres) in 1948 to a maximum of 1.75 million sq. meters (435 acres) in 2014 (Table 6-2; Figure 6-2). Improved resolution of 2005 and 2014 imagery, which enables better detection and delineation of dune areas, may account for minor variations in dune area, but the overall trend is of dune area expansion with little or no change in the main and more densely vegetated dunes. With one or two exceptions (discussed below) there is little evidence for widespread migration of dunes and most well-developed dune features can be identified on images throughout the period of record (Figure 6-2).

6.3 CHANGE DETECTIONS AND ANALYSIS

Detection of changes in dune extent was evaluated from the imagery and performed at a resolution of 10-meter (32.8 feet) cell size. Raster data for each year (1948, 1971, 1984, 2004, 2014) were classified so that the cells containing dune features could be calculated as areas of erosion (-1), deposition (+1), or no change (2) upon subtraction from over a maximum of five time step intervals (e.g., raster data 1948 minus raster data 1971).

The results of the change detection analysis indicate that there has been an overall increase in the area of stable dunes, which is interpreted as overall dune field stabilization with time (Figures 6-3 and 6-4). The proportion of dune features that exhibited erosion decreased over time; whereas, areas of deposition remained fairly constant or increased slightly (Figures 6-3 and 6-4).

Documented changes are likely related to subtle degrees of erosion and/or deposition of relatively small, low relief, and less vegetated dune features that are isolated in the dune field or along the margins of prominent and stable dune features.

6.3.1 Decadal- to Bi-Decadal-Scale Changes in Dune Feature Extent Near SNORT

Decadal- to bi-decadal-scale changes in dune feature extent were assessed for four time intervals using the available imagery. The period 1948 to 1971 is characterized by expansion (i.e., deposition) of dune features, especially in the area east of SNORT (Figures 6-3 and 6-4). From 1971 to 1984, many dune features west of SNORT experienced contraction (i.e., erosion), with limited dune deposition and minor erosion immediately east of SNORT (Figures 6-3 and 6-4). The period 1984 to 2004, is characterized by erosion that is likely associated with sand deposited in the previous interval in areas immediately east of SNORT, as well as localized deposition of sand in the far western and southeastern sectors of the evaluated area (Figures 6-3 and 6-4). The interval from 2004 to 2014 was characterized by a general increase in the area of dunes that exhibited no change, and by deposition of sand in areas east and northeast of the SNORT alignment (Figures 6-3 and 6-4).

Calculation of net (deposition minus erosion) and total (deposition plus erosion) change in the dune field was also performed over the four intervals to provide insight on the decadal- to bi-decadal-scale dune behavior near the SNORT alignment between 1948 and 2014 (Figures 6-5 and 6-6). The dune field change was net negative (erosional) from 1971 to 1984, whereas change during the three other intervals were either net positive (depositional) or nearly in equilibrium (value of -490). The maximum total amount of change occurred during the interval 1971 to 1984, indicating that the dune field was most active during this period (Figure 6-6). This is also the interval during which the dune field extent decreased and experienced the greatest percent of erosion (Figure 6-4). Total change has decreased slightly since this interval, the possible causes of these variations are discussed below in Section 6.4.

6.3.2 Site-Specific Changes Near KTM 1001

While the majority of dune features experienced minor changes in areal extent over the analysis period, there is limited evidence for systematic and widespread dune migration and sand encroachment in the vicinity of the SNORT alignment, except for one localized area downwind and east of the SNORT alignment adjacent to KTM 1001 (for location see Fig. 3-9). This localized area, experienced measurable change from 1948 to 1971, but less change until 2014 (Figure 6-7).

The landscape in the area of KTM 1001 in 1948 was dominated by a large N-S oriented dune ridge with a small parabolic dune on its eastern side (Figure 6-7a). Several roads that branch northwest from Baker Access Road are identified in this dune area and provide reference points for dune activity. This same area changed measurably by 1971 where the N-S dune ridge and underlying sediment had been deeply excavated for borrow material during construction of KTM 1001. By 1971 several new roads and tracks crossed the area, and a well-developed parabolic dune had formed to the downwind of the KTM 1001 construction site and disturbed dune surfaces. By 1984 the same parabolic dune had migrated eastward several hundred meters (yards), and had transformed into a complex of three main parallel dune ridges and one smaller dune ridge that had crossed one of the northwest oriented road branches (Figure 6-7bc). In 2004, the smaller dune

ridge had grown in extent and the migrating parabolic dune complex had extended farther to the east (Figure 6-7d). From 2004 to 2014, the area of the parabolic dune complex exhibited relatively minor downwind expansion.

The rate of eastward dune expansion of the parabolic dune complex declined steadily over time from a maximum of 6.43 m (21.09 ft) per year between 1948 and 1971 to 1.2 m (3.94 ft) per year between 2004 and 2014 (Figure 6-8). Dune expansion during the 1948 to 1971 interval is considered a minimum, because it is not known when the initial disturbance and construction of KTM 1001 occurred.

The majority of change in the parabolic dune complex occurred between 1948 and 1971 and was followed by greater degrees of dune stability reflected by an increase in the dune areas that had no change (Figure 6-9). The dune change analysis at the KTM 1001 site clearly indicates the high risk for dune mobilization and sand encroachment as a result of disturbance of dune-covered areas by infrastructure development, off-road driving, or shallow and deep excavations.

6.4 CONTROL OF DUNE CHANGE

6.4.1 Climatic Drivers

The dynamics of dune systems on all time scales are governed by the supply of sand, sand available for transport, and the sand transport capacity of the wind (Kocurek and Lancaster, 1999). In the SNORT study area (and the Mojave Desert in general) sand transport, sand availability, soil moisture, and wind are key components of the eolian system, such as: (1) sand supply is governed by the erosion, transport, and deposition of material by fluvial processes; (2) sand availability is a function of vegetation cover, soil moisture, and presence of erosion-resistant crusts; and (3) the transport capacity in this area is governed by the magnitude and frequency of strong winds, which is strongly influenced by the frequency of frontal weather systems that affect the area in late winter and spring (see Section 2 of this report).

To evaluate possible drivers of change we compared rates and patterns of change in dune extent to climate proxies, including annual Palmer Drought Severity index (PDSI), equatorial Pacific sea surface temperature indices of 'Niño 3 SST' and 'Niño 3.4 SST' along with the southern oscillation index (SOI), and threshold wind speed records for the region.

6.4.1.1 Palmer Drought Severity Index

PDSI was calculated using the MATLAB code of Jacobi et al. (2013), historical 4-km interpolated Parameter Elevation Regression on Independent Slopes Model (PRISM) monthly precipitation and temperature estimates (Daly et al., 2008) for the centroid of the SNORT study area, and correlated soil characteristics from similar landforms in Owens Valley (Tallyn, 2002). Analysis of dune extent and mean PDSI for each of the four time intervals between 1948 and 2014 show that rates of dune extent change are inversely related to PDSI (Figure 6-10). These relations indicate that the dune field becomes net erosional during periods of less negative PDSI (wetter conditions). In addition, there is a strong linear correlation between rates of erosion and mean PDSI ($R^2 = 0.81$), suggesting that the dune system contracts during wetter climatic conditions and

expands during drier conditions. The correlation between rates of total activity and mean PDSI is, however, weaker ($R^2 = 0.50$), largely because rates of deposition are weakly related to mean PDSI ($R^2 = 0.22$). This implies, counter-intuitively, that the system is more active during relatively wetter periods.

6.4.1.2 Sea Surface Temperature Indices

Sea surface temperature anomalies characterized by monthly Niño 3 and 3.4 indices from the eastern and middle Pacific Ocean, respectively, are commonly used to monitor the strength of the El Niño/Southern Oscillation (ENSO) (Figure 6-11A). Decadal variations in the strength of ENSO commonly controls surface climate and precipitation variability in the western U.S. (e.g., Redmond and Koch, 1991; McCabe and Dettinger, 1999). The four time intervals between 1948 and 2014 analyzed for total dune activity were correlated with mean summer/fall (June-November) Niño 3 and 3.4 SST indices (data from Rayner et al. (2002)) (Figure 6-11B). There is a strong correlation between total dune activity and the maximum summer-fall Niño 3 SST index ($R^2 = 0.549$) (Figure 6-12A), and a slightly weaker correlation with the maximum summer/fall Niño 3.4 SST index ($R^2 = 0.491$) (Figure 6-12B). Similar relations are found for total dune activity and maximum Niño 3 and 3.4 SST indices ($r^2 = 0.649$ and 0.850 , respectively). In contrast, there is an inverse relation between net dune area change and both Niño SST indices (Figure 6-13). The dune field is net erosional or neutral in times of relatively higher Niño SST index values. These relations can be explained in part by a pattern of increased winds and sand transport during periods of relatively stronger El Niño conditions (positive Niño 3 and Niño 3.4 SST indices), despite the increase in precipitation that often accompanies such conditions.

6.4.1.3 Threshold Wind Events

A number of studies have shown strong correlation between ENSO patterns and regional winds. For example, Berg et al. (2013) reported a strong correlation between relatively strong El Niño conditions and increased wind speed compared to precipitation in coastal southern California. This is supported by the study of Bromirski et al. (2003) in coastal northern California that found decadal-scale patterns of storminess related to large-scale patterns of atmospheric circulation in the northern Pacific that are often modulated by ENSO patterns. At this latitude of the western U.S., periods of increased storminess are associated with southerly shifts in the position of the Aleutian low, directing storm tracks towards northern and central California.

Increased periods of strong winds associated with passage of mid-latitude frontal systems has been documented for areas north of China Lake (Shiyuan et al., 2008) and the regional nature of major wind events has been demonstrated (Saint-Amand et al., 1996; Shiyuan et al., 2008). We hypothesize that overall wind intensity (a function of velocity and duration of wind) in the region of Indian Wells Valley should increase as a result of more periods of strong winds associated with passage of mid-latitude frontal systems. To test this hypothesis, we treated data with multiple linear regression analysis that included the correlation of regional patterns of wind speed with the Niño 3 SST index, the southern oscillation index (SOI), and PRISM precipitation estimates over the period from water year 1991 to 2011.

Because the dataset for historical wind speed in Indian Wells Valley is incomplete, we used 20 years of continuous hourly wind speed data from the Great Basin Unified Air Pollution Control

District's meteorological (A-Tower) site at the northern margin of Owens (playa) Lake. Although about 95 km (60 mi) distance separates the A-Tower site and the SNORT study area, and wind patterns may vary between the two areas, this wind speed data set is used to develop an index of regional-scale wind storminess.

Hourly wind speed data was aggregated into the total number of winter (October–March) wind speed events that were greater than or equal to 7 m/s (15.7 mph) (Table 6-3), to develop an index of wind intensity or storminess. This is the same minimum threshold wind speed used in the analysis of high wind events in the Owens Valley by Shiyuan et al. (2008) as well as in section 2 of this report.

Monthly Niño 3 SST index data of Rayner et al. (2002) and monthly standardized SOI data from NOAA (2016) were both aggregated into mean summer/fall annual values (Table 6-4). Similar to the Niño 3 and 3.4 SST indices, SOI is used as an indicator of the strength of ENSO conditions and is an index of the atmospheric pressure differences across the tropical Pacific Ocean between Tahiti and Darwin, Australia (e.g., McCabe and Dettinger, 1999). Both types of indices derived from the Pacific Ocean are inversely correlated with each other and with hydroclimatic variability in the western U.S. (e.g., Redmond and Koch, 1991; McCabe and Dettinger, 1999). Both indices are used in the regression analysis to represent an index or proxy for relative storminess along the south-eastern Sierra Nevada.

Monthly PRISM precipitation estimates from interpolated locations at Mammoth Pass in the Sierra Nevada and at Sheep Mountain in the White Mountains were aggregated into total winter (October–March) and annual values (Table 6-3). These two sites were chosen because they are able to provide data on the precipitation gradient across the valley by virtue of their similar latitude and locations at the crests of the mountain ranges bounding Owens Valley. The multiple linear regression analysis yielded a statistically significant and moderately-strong correlation between winter wind speed (≥ 7 m/s) and winter White Mountains precipitation, summer/fall Niño 3 SST index, and summer/fall SOI ($R^2 = 0.63$; $p = 0.006$). The precipitation dataset from Mammoth Pass did not help strengthen correlations, therefore it appears that the atmospheric circulation patterns associated with precipitation in the White Mountains also are reflected by stronger winds in the valley.

The above analyses indicate that, at a regional scale, the moderately strong correlations between proxy indices of storminess in the eastern Sierra Nevada and indices of ENSO conditions in the Pacific Ocean support a global climate linkage to periods of increased high intensity wind events and eolian activity. The increase in high intensity wind events associated with powerful frontal storm systems is considered to be a contributor to sand movement in the Owens and Indian Wells valleys.

6.4.2 Influence of Groundwater and Active Faulting

Groundwater has played an important role in the eolian geomorphology of the SNORT study area, in particular through its influence on groundwater-dependent plant communities, which are the primary vegetation type that stabilizes dunes in the study area. The Little Lake fault zone (LLFZ) has recently been recognized as an important factor in the behavior of the basin-wide,

shallow groundwater system (see section 3.3), and is associated with measurable differences in groundwater levels and rates of change on each side of, and within the fault zone.

In order to assess the possible effects of changes in groundwater level on the dune system, the SNORT study area was divided into two parts (east and west) along the trend of the LLFZ. Rates and patterns of dune change were evaluated and compared on each side of the fault zone (Table 6-5). West of the LLFZ, groundwater levels declined at an increasing rate over the 96-year long period of record; whereas east of the LLFZ, rates remained similar over the period, but since 1985 were generally lower, by a factor of 3, than those west of the fault zone. Collectively, the change in groundwater levels over the period of record from 1920 to 2016 was similar at -4.07 to -4.85 m (-15.95 to -13.36 ft.) taken from the centroid within the east and west areas, which are about 1.6 and 2.4 km (1.0 and 1.5 mi), respectively from the fault zone.

The change in dune extent for the same areas is generally higher in the east compared to the west area, but both areas exhibit a similar pattern of increasing stability (no change) over the period analyzed (Figure 6-14). Analysis of the normalized rate of change per year in dune extent for each time interval indicates that the rate of change is greater in the eastern area (Figure 6-15). In addition, the amount of dune extent change in the west area decreased steadily over time. Both areas show net dune erosion between 1971 and 1984 and net dune deposition during the other time intervals.

Overall, it appears that there are no measurable differences in dune field areas or behavior on either side of the LLFZ at distances greater than about 200 m (660 ft) that can be detected in this analysis. However, it should be noted that although the total decline in groundwater levels on each side of the LLFZ is similar, east of the fault zone the absolute groundwater levels are closer to the surface (see Figure 3-9 in section 3 of this report). Consequently, a 4-5 m (13–17 ft) decline in groundwater level east of the LLFZ has greater potential to affect groundwater-sensitive plant communities and destabilize vegetated dunes. Evidence that this has occurred recently is documented by the presence of dead vegetation and vegetation loss, which has resulted in blowouts in small dunes southeast of the KTM 1001 site (Figure 6-16).

6.5 CONCLUSIONS

Aerial photographic evidence suggests that the dune system in the vicinity of the northern SNORT alignment has not changed significantly since 1948 and in general is becoming more stable over time, although local disturbance (e.g. east of the KTM 1001 trench site) has caused significant local change. We tested the hypothesis that levels of change (dune activity) and the style of change (erosion or deposition) in the dune system are related to variations in the magnitude and duration of wind events capable of moving sand. In turn, these events appear to be more frequent during times of El Niño (positive) conditions which give rise to increased frequency of cyclonic weather systems affecting the area. Although such meteorological conditions may bring increased precipitation to the region, this may not be significant to the groundwater-dependent vegetation community that currently stabilizes the dunes. Lowering of the water table, however, especially east of the LLFZ as a result of groundwater withdrawals, has the potential to adversely affect these vegetation communities and lead to reduction in vegetation cover and destabilize presently vegetated dunes that have been relatively stable for about two thousand years.

7.0 SUMMARY AND CONCLUSIONS

The primary objective of this study was to provide NAWCWD with the information needed to: (1) assess the sand and dust hazards to existing and planned facilities in the vicinity of SNORT and (2) develop sustainable long-term mitigation and control of sand encroachment and dust emissions to protect these facilities. The study conducted field, office, and laboratory studies of eolian (wind transported and deposited) sediments and landforms in the vicinity of the SNORT Facility.

The SNORT study area contains a variety of landforms and deposits, reflecting its location between alluvial fans extending from the Sierra Nevada on the west and southwest and the central playa area of China Lake to the east. Eolian deposits are widespread, mainly in the eastern two-thirds of the SNORT study area and overlie alluvial, lacustrine/deltaic, and playa deposits. The formation and occurrence of dunes and sand sheets in the SNORT study area is strongly influenced by the depth to the shallow groundwater table, which in turn is controlled by the location of the active Little Lake fault zone (LLFZ) and the Airport Lake fault zone (ALFZ). Vegetated sand dunes have accumulated in two discrete areas that coincide with (1) the graben situated at the intersection of the LLFZ and ALFZ, and (2) the axis of the broad fluvial plain west of the graben and SNORT. The eastern area of dunes is covered by a well-established, groundwater-dependent greasewood-sacaton plant community, which is very sensitive to relative changes in shallow groundwater levels. In contrast, the areas of dunes along the axis of the fluvial plain west of the graben are much lower in relief and less vegetated.

The mineral composition of the sand comprising these landforms indicates that the principal source was the southern Sierra Nevada, and was transported to the study area by ephemeral washes. In present-day conditions, little or no sand reaches the study area from these sources. The sedimentary record of eolian deposition and luminescence dating in the study area, revealed by a preexisting trench in the vicinity of the KTM 1001 site, indicates that two periods of sand deposition occurred at 0.92–1.22 and 2.0–2.14 ka.

The existing sand dunes and sand sheets that occur in the SNORT area are largely stabilized by vegetation and have not appreciably changed shape and extent over the period for which aerial photographs and satellite images are available (1948 to 2015). Sand mobilization and encroachment on facilities and infrastructure is limited to areas of the north end of the SNORT alignment and to the Baker Access Road where it passes through the eastern (downwind) area of the dune belt.

Very little net change in dune extent was detected over the period for which data is available, indicating that the dunes in the vicinity of SNORT have not undergone a systematic change in position or area over time. However, measurable change from year to year was detected using imagery, indicating that sand is being moved around within the dune and sand sheet areas, but is not contributing to an overall change in dune position and/or extent. Variations in the relative

degree of change from one period to another are correlated with indices of relative ENSO strength, which our analyses suggest can affect the frequency and magnitude of wind storms in the area.

7.1 SAND AND DUST HAZARDS AND THEIR MANAGEMENT IMPLICATIONS

7.1.1 SAND ENCROACHMENT

Anthropogenic disturbance of the dune system via vegetation removal or excavations has the potential to cause significant sand movement and formation of new dune areas. This is demonstrated by the formation of blowouts and parabolic dunes downwind of the KTM 1001 site. Many of the dunes are stabilized by groundwater-dependent vegetation. Lowering of the shallow water table as a result of groundwater withdrawal or climate change or a combination of both has the potential to destabilize the eolian system, especially in areas to the east of the Little Lake fault zone, where the water table is relatively close to the surface.

Destabilization of the less vegetated and low-relief dunes west of the SNORT muzzle poses a hazard of sand transport from westerly winds and deposition onto the track. Destabilization of the larger expanse of moderately vegetated and high-relief dunes within the fault zones poses a hazard of sand transport from westerly winds and deposition across Baker Access Road. Continued sand transport east of the Baker Access Road poses the additional hazard of initiating dust-generating events as a result of sand abrasion across the silt-rich fluvial plain and playa surfaces in the area and have the potential to impact visibility and air quality.

While not included within the study area, continued land-disturbing agricultural activity along Brown Road west of the NAWS China Lake fence is a source of sand and dust moving eastward onto the installation from westerly winds. Observations (February (2016) along the boundary fence suggests that sand encroachment occurs immediately adjacent to and downwind (east) of agricultural areas that were abandoned. At the time the agricultural areas were sparsely vegetated or un-vegetated. There is no evidence for large scale sand encroachment from this source, although local impairment of boundary fences and roads has occurred.

7.1.2 Dust Hazards

Sand in the vicinity of SNORT contains 4 to 8 percent by weight silt and clay-sized material, with higher amounts in the sub-surface of vegetation-stabilized dunes, and as much as 4-6 percent in mobile sand deposits. If the vegetation that stabilizes the dunes today were to be diminished by drought or groundwater decline, the dunes could become mobilized, and the consequent movement of sand could release large amounts of airborne dust.

Although the percentage of fine (i.e., dust) material is relatively small, the mass of silt- and clay-size material is large and is susceptible to emissions under certain conditions. Assuming a bulk density for sandy soil of 1.6 gm/cc; and a silt and clay content of 5 percent, then each cubic meter (35 cubic feet) of sand could contain up to 80 kg (176 lbs.) of fine material. Laser particle size analyses of the silt- and clay-sized fraction shows that 68 percent of this material is smaller than 10µm (microns) in diameter, which places it into the PM10 emissions category. The total

area of sand deposits in the study area in 2014 was estimated to be 670,132 square meters (801,451 sq. yards). Assuming an average sand depth of 1 m (3.28 ft) across the area and the mobilization of only 10 percent of this area as a result of drought or disturbance, there is the potential for release of more than 5000 metric tons (5500 US tons) of fine material. Because 68 percent of the fine material falls within the, PM10 emissions range, there is a potentially significant amount of fugitive dust contained in the SNORT area dunes.

A specific example of the potential effects of disturbance is given by the formation of a 36,000-square meters (43,056 sq. yards) blowout dune downwind (east of the KTM 1001 excavation) between 1948 and 1971. Assuming an initial silt and clay content of 5 percent in the sediments that were mobilized and a final silt and clay content of 2 percent, approximately 52 metric tons (57 US tons) of material smaller than PM10 could potentially have been emitted each year.

7.2 RECOMMENDATIONS

Based on the above estimates for the potential for dust production from dune disturbance or mobilization, it is recommended that protection of existing sand surfaces and landforms from disturbance be a priority with the goal of avoiding sand mobilization and the probability of consequent dust emissions. If disturbance of dune areas is necessary for facility operations, then priority should be placed on post-disturbance protection of the surface using re-vegetation or deployment of artificial roughness elements (e.g., straw bales, sand fences). Such procedures have been shown to be effective and sustainable in many coastal dune environments, as well as at Owens Lake, California (Gillies et al., 2015).

In view of the high potential for dust emissions from disturbed sand surfaces adjacent to SNORT, it is recommended that detailed follow-up studies of dust emissions be conducted on potentially emissive surfaces using a portable wind erosion laboratory such as the DRI PISWERL device (Etymezian et al, 2007). These follow up studies are critical to determining emission factors and threshold wind speeds for dust emission associated with specific landform types. Using the detailed mapping of landforms conducted in this study and by previous mapping (Bacon et al., 2015; Bullard et al., 2015), it will then be possible to develop a dust emissions inventory to better identify and predict the extent of potential dust emitters, constrain the potential for dust emissions, and to develop sustainable dust control measures. Similar studies should also be conducted on the abandoned agricultural areas west of the NAWS China Lake fence near Brown Road to better understand the potential hazard with respect to sand and dust and to develop dust and sand control measures for this area, as well as other potential dust emitting areas east and northeast of the SNORT study area.

Consideration should be given to augmenting the proposed network of eddy covariance towers to include sand transport and dust sensors so that sand movement and dust emissions can be correlated directly with meteorological variables in key areas.

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9.0 TABLES

TABLE 4-1. Results of Infrared Stimulated Luminescence (IRSL) Analysis of Sediment Sampled at KTM 1001 Study Site.

Field ID number	Lab Sample number	Depth (m)	Location (decimal degrees)	Altitude (m)	N accepted (N analyzed) ^a	D _b (Gy) ^b	U (ppm) ^c	Th (ppm) ^c	K (%) ^c	External beta dose rate wet (Gy/ka)	External gamma dose rate wet (Gy/ka)	Cosmic dose rate (Gy/ka) ^d	Total dose rate (Gy/ka) ^e	Faded Age (ka) ^f	Corrected Age (ka) ^g
CL-16-1	CLMT001	1.0	33.2357°N 103.9043°E	670	45 (48)	6.74 ± 0.2	2.42	6.24	2.19	2.04	1.11	0.21	3.41 ± 0.18	1.98 ± 0.12	2.14 ± 0.23
CL-16-2	CLMT002	1.2			38 (39)	3.84 ± 0.13	2.46	7.29	2.28	2.08	1.16	0.20	3.50 ± 0.19	1.10 ± 0.07	1.19 ± 0.12
CL-16-3	CLMT003	0.5			42 (48)	3.4 ± 0.11	2.68	6.14	2.22	2.06	1.12	0.24	3.47 ± 0.18	0.98 ± 0.06	1.06 ± 0.12
CL-16-4	CLMT004	0.5			37 (39)	3.43 ± 0.11	2.74	12.75	2.13	2.12	1.41	0.24	3.85 ± 0.19	0.89 ± 0.05	0.96 ± 0.10
CL-16-5	CLMT005	0.3			41 (48)	3.48 ± 0.11	2.28	4.91	2.39	2.12	1.07	0.25	3.49 ± 0.19	1.00 ± 0.06	1.08 ± 0.12
CL-16-6	CLMT006	0.4			40 (46)	3.04 ± 0.097	2.00	6.68	2.41	2.14	1.13	0.25	3.56 ± 0.20	0.85 ± 0.05	0.92 ± 0.10
CL-16-7	CLMT007	0.5			23 (41)	6.08 ± 0.26	2.84	7.00	1.97	1.88	1.10	0.24	3.28 ± 0.17	1.85 ± 0.12	2.00 ± 0.23
CL-16-8	CLMT008	0.6			35 (40)	6.39 ± 0.022	2.08	4.05	2.30	2.01	0.99	0.23	3.27 ± 0.19	1.96 ± 0.11	2.00 ± 0.23
CL-16-9	CLMT009	1.0			39 (41)	3.72 ± 0.12	2.04	5.74	2.25	2.00	1.05	0.21	3.30 ± 0.18	1.13 ± 0.07	1.22 ± 0.13
CL-16-10	CLMT010	1.4			44 (44)	64.44 ± 1.96	3.38	12.85	2.22	1.89	1.27	0.20	3.43 ± 0.27	18.80 ± 1.59	21.12 ± 2.97

^a n is the number of D_e determinations accepted after screening; in parentheses are the total number of aliquots measured.

^b The error shown on the burial dose, D_b is the error modeled with the central age model (CAM) (Galbraith et al, 1999). Overdispersion for all samples is < 1%.

^c U and Th samples were fused with lithium borate and measured with ICP-MS. K₂O was measured on bulk sample with ICP-AES and converted to % K.

^d Cosmic dose rates (Gy/ka) are calculated according to Prescott and Hutton (1994).

^e Dose rates (Gy/ka) were calculated using the conversion factors of Liritzis et al. 2013 and are shown rounded to two decimal places; ages were calculated using values prior to rounding; central values are given for dose-rates and errors are incorporated into that given for the total dose-rate. Water content of 2% ± 1% was used for dose rate calculations for samples CLMT001-009. Water content of 20% ± 10% was used for CLMT 010 based on the field measured water content and consideration for the lacustrine field context.

^f Luminescence ages were calculated using DRACv1.2 (Durcan et al., 2015) and are expressed as thousands of years before 2018 and rounded to the nearest 10 years. Error is 1 sigma.

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TABLE 5-1. Location of China Lake Sand Sampling Sites (UTM Zone 11), NAD 83 Datum.

Sample number	Easting	Northing	Location Information
CL-16-1 to CL-16-10	434418.530	3953866.800	KTM 1001 Trench
CL-16-11	434203.560	3954872.802	crest parabolic dune
CL-16-12	447895.852	3953129.546	east side of China Lake playa
CL-16-13	441788.862	3954767.468	rolling sand sheet at Kennedy dunes
CL-16-14	441702.032	3954898.762	rolling sand sheet at Kennedy dunes
CL-16-15	439858.192	3954876.298	sand sheet with small rolling dunes
CL-16-16	432855.881	3954294.875	disturbed sand west of SNORT track
CL-16-17	432855.881	3954294.875	sand banked up against SNORT track
CL-16-18	425764.484	3953200.165	fence line dune
CL-16-19	425405.575	3954358.579	fence line dune
CL-16-20	434622.992	3953870.505	blowout dune SE of KTM 1001 trench
CL-16-21	420759.085	3951747.528	wash at Short Canyon

TABLE 5-2. Summary of Particle Size and Chemical Analyses of China Lake Sand Samples.

Field ID	Soil Moisture (g/g)	% wt. Gravel	2.0-1.0 mm %wt.	1.0-0.5 mm %wt.	0.5-0.25 mm %wt.	0.25-0.125 mm %wt.	0.125-0.0625 mm %wt.	Total Sand %wt	Total Silt & Clay %wt.	EC - mg g ⁻¹ -	CaCO ₃ - % -
CL-16-1	0.02	0.0	0.0	1.2	35.2	47.6	9.5	93.5	6.5	931.8	5.3
CL-16-2	0.05	0.0	2.5	20.8	35.6	23.7	8.1	90.7	9.3	670.4	7.8
CL-16-3	0.04	0.0	0.0	1.3	30.6	45.1	13.1	90.2	9.8	777.2	7.5
CL-16-4	0.05	0.0	0.0	0.3	13.8	56.4	19.2	89.8	10.2	673.8	7.9
CL-16-5	0.02	0.0	1.4	27.9	37.7	20.7	6.6	94.2	5.8	260.5	5.8
CL-16-6	0.02	0.0	0.7	17.9	38.0	29.9	7.3	93.8	6.2	175.3	5.6
CL-16-7	0.06	0.0	0.0	0.3	7.2	53.3	27.2	88.1	11.9	5034.9	8.8
CL-16-8	0.03	0.0	0.3	27.4	36.2	21.1	7.8	92.9	7.1	777.4	5.8
CL-16-9	0.03	0.0	0.1	17.9	42.3	26.2	7.8	94.2	5.8	347.8	5.7
CL-16-11	0.02	0.0	0.6	26.5	40.2	25.2	3.4	95.9	4.1	172.5	2.0
CL-16-12	0.03	0.0	2.9	18.5	32.1	33.0	10.4	96.9	3.1	129.5	1.1
CL-16-13	0.02	0.4	28.2	25.2	15.7	19.5	8.9	97.6	2.4	85.8	0.6
CL-16-14	0.02	0.0	2.2	18.3	32.8	32.2	12.0	97.5	2.5	108.6	0.3
CL-16-15	0.02	2.4	22.0	22.1	22.2	21.2	8.1	95.6	4.4	111.0	0.6
CL-16-16	0.04	0.0	0.7	22.3	43.4	22.3	4.8	93.5	6.5	233.3	4.9
CL-16-17	0.04	0.0	0.0	1.8	47.7	36.7	6.3	92.4	7.6	262.2	3.3
CL-16-18	0.02	0.0	0.1	14.0	40.8	33.0	8.9	96.7	3.3	197.2	0.2
CL-16-19	0.01	0.0	3.0	50.1	24.5	13.1	5.9	96.5	3.5	224.6	0.2
CL-16-20	0.03	0.0	0.1	3.9	30.8	46.4	12.7	93.8	6.2	2763.5	5.5
CL-16-21	0.03	17.7	10.2	29.6	29.0	16.1	7.3	92.2	7.8	26.5	0.1

TABLE 5-3. Particle Size and Sorting Parameters for China Lake Sand Samples.

Sample Number	Mean GS (µm)	Mean GS (phi)	Sorting (phi)	Skewness
CL-16-1	207.1	2.44	0.66	0.16
CL-16-2	337.2	1.90	0.96	0.09
CL-16-3	198.9	2.52	0.70	0.09
CL-16-4	160.8	2.79	0.61	-0.11
CL-16-5	356.6	1.78	0.92	0.35
CL-16-6	301.5	2.01	0.88	0.06
CL-16-7	142.8	2.96	0.59	-0.21
CL-16-8	341.6	1.84	0.92	0.41
CL-16-9	300.5	1.99	0.85	0.26
CL-16-11	171.4	2.62	0.75	0.34
CL-16-12	152.4	2.53	0.85	0.54
CL-16-13	293.0	1.85	1.09	0.80
CL-16-14	147.0	2.50	0.83	0.73
CL-16-15	261.5	2.04	1.07	0.53
CL-16-16	165.7	2.58	0.72	0.48
CL-16-17	114.9	2.93	0.55	1.03
CL-16-18	134.7	2.68	0.71	0.75
CL-16-19	224.7	2.13	0.76	1.15
CL-16-20	101.0	2.81	0.68	1.00
CL-16-21	225.4	2.16	0.90	0.56

TABLE 5-4. Semi-Quantitative Estimates of Mineral Composition of China Lake Sand Samples.

Field ID	Quartz	Plagioclase	K-feldspar	Calcite
CL-16-1	37.5	43.6	11.1	7.8
CL-16-2	40	39.2	11.9	8.9
CL-16-3	34.5	43.2	13	9.3
CL-16-4	32.2	46.9	10.9	10
CL-16-5	43.1	36	11.7	9.2
CL-16-6	40	39.6	11.8	8.6
CL-16-7	27.7	47.4	10.1	14.8
CL-16-8	42.6	37.7	12.2	7.5
CL-16-9	42.5	40.5	10.7	6.3
CL-16-11	42.8	43.7	13.5	Trace
CL-16-12	36.8	47.1	16.1	Trace
CL-16-13	35.5	47.3	17.2	Trace
CL-16-14	39.7	45.4	14.9	Trace
CL-16-15	38.7	45.9	15.4	Trace
CL-16-16	43.7	40.2	11.1	5
CL-16-17	39.2	43.8	9.5	7.5
CL-16-18	38.4	50.2	11.4	-
CL-16-19	42.9	44.5	12.6	-
CL-16-20	37.4	42.3	12.4	7.9
CL-16-21	49	32.1	18.9	-

TABLE 6-1. Details on Date, Scale/Resolution, and Type of Aerial Photograph and Imagery Used in Study.

Date of Images	Horizontal Scale/Resolution	Image Type
9/30/48	1:47,200	USGS Black and white photograph
7/11/71	1:12,000	USGS Black and white photograph
9/22/84	1:58,000	Color infra-red aerial photographs
2004	1 meter	NAIP color imagery
2014	1 meter	NAIP color imagery

Note: National Agriculture Imagery Program (NAIP)

TABLE 6-2. Distribution of Dune Features in Vicinity of Northern SNORT Alignment Over 66-Year Period of Record.

Year	Dune Area (sq m)	Dune Area (sq yds)	Dune Area (ha)	Dune Area (acres)
1948	1,094,308	1,308,781	109	270
1971	1,662,033	1,987,775	166	411
1984	1,388,936	1,661,154	139	343
2005	1,385,400	1,656,925	139	342
2014	1,755,929	2,100,074	176	434

TABLE 6-3. Winter (October-March) Precipitation From the White Mountains and Sierra Nevada and Hourly Wind Speed From Owens (Playa) Lake Used in Multiple Linear Regression Analysis.

Water Year	White Mountains Precipitation (mm)	Sierra Nevada Precipitation (mm)	Number of Hourly Wind Events ≥ 7 m/s from October-March
1991	314	590	590
1992	269	573	544
1993	501	1084	501
1994	219	356	798
1995	583	1217	781
1996	434	839	535
1997	528	1323	750
1998	461	872	842
1999	205	778	904
2000	201	641	818
2001	297	606	729
2002	224	743	660
2003	297	650	621
2004	218	651	646
2005	598	1280	913
2006	477	1082	705
2007	174	457	857
2008	349	890	772
2009	310	886	789
2010	372	948	736
2011	532	1481	839

Notes: White Mountains PRISM 4-km precipitation estimate from near Sheep Mountains (Lat: 37.5200, long: -118.20, elev.: 3282 m).

Sierra Nevada PRISM 4-km precipitation estimate from Mammoth Mountain pass (lat: 37.6113, long: -119.0320, elev.: 2883 m).

TABLE 6-4. Summer/Fall (June-November) Niño 3 Sea Surface Temperature (SST) and Southern Oscillation Index (SOI) Indices Used in Multiple Linear Regression Analysis.

Water Year	Mean June-October Niño 3 SST index	Average June-October SOI
1990	-0.023	-0.050
1991	0.580	-0.617
1992	-0.148	-0.467
1993	0.197	-0.733
1994	0.148	-1.033
1995	-0.515	0.183
1996	-0.348	0.617
1997	2.645	-1.283
1998	-0.377	1.083
1999	-0.932	0.517
2000	-0.537	0.683
2001	-0.413	0.100
2002	0.618	-0.533
2003	0.057	-0.100
2004	0.220	-0.450
2005	-0.202	0.283
2006	0.470	-0.600
2007	-1.097	0.400
2008	0.115	0.950
2009	0.842	-0.233
2010	-1.173	1.533

TABLE 6-5. Change in Groundwater Levels on West and East Sides of Little Lake Fault Zone (LLFZ).

Period	Change in Groundwater Level			
	west of LLFZ		east of LLFZ	
	m	ft	m	ft
1920 - 1985	-1.62	-5.31	-3.07	-10.07
1985 - 2006	-2.13	-6.99	-0.66	-2.17
2006 -2016*	-1.11	-3.64	-0.34	-1.12
1920 - 2016	-4.86	-15.95	-4.07	-13.36

*Change in groundwater between 2006 and 2016 calculated using rates of -0.101 m/yr (-0.331 ft/yr) and -0.031 m/yr (0.102 ft/yr) for west and east sides of LLFZ, respectively (see Section 3.0 for discussion on rates).

Hourly wind speed from the Great Basin Unified Air Pollution Control District A-Tower meteorological station at Owens (playa) Lake (lat: 36.524, long: -117.944, elev.: 1090.3 m).

10.0 FIGURES

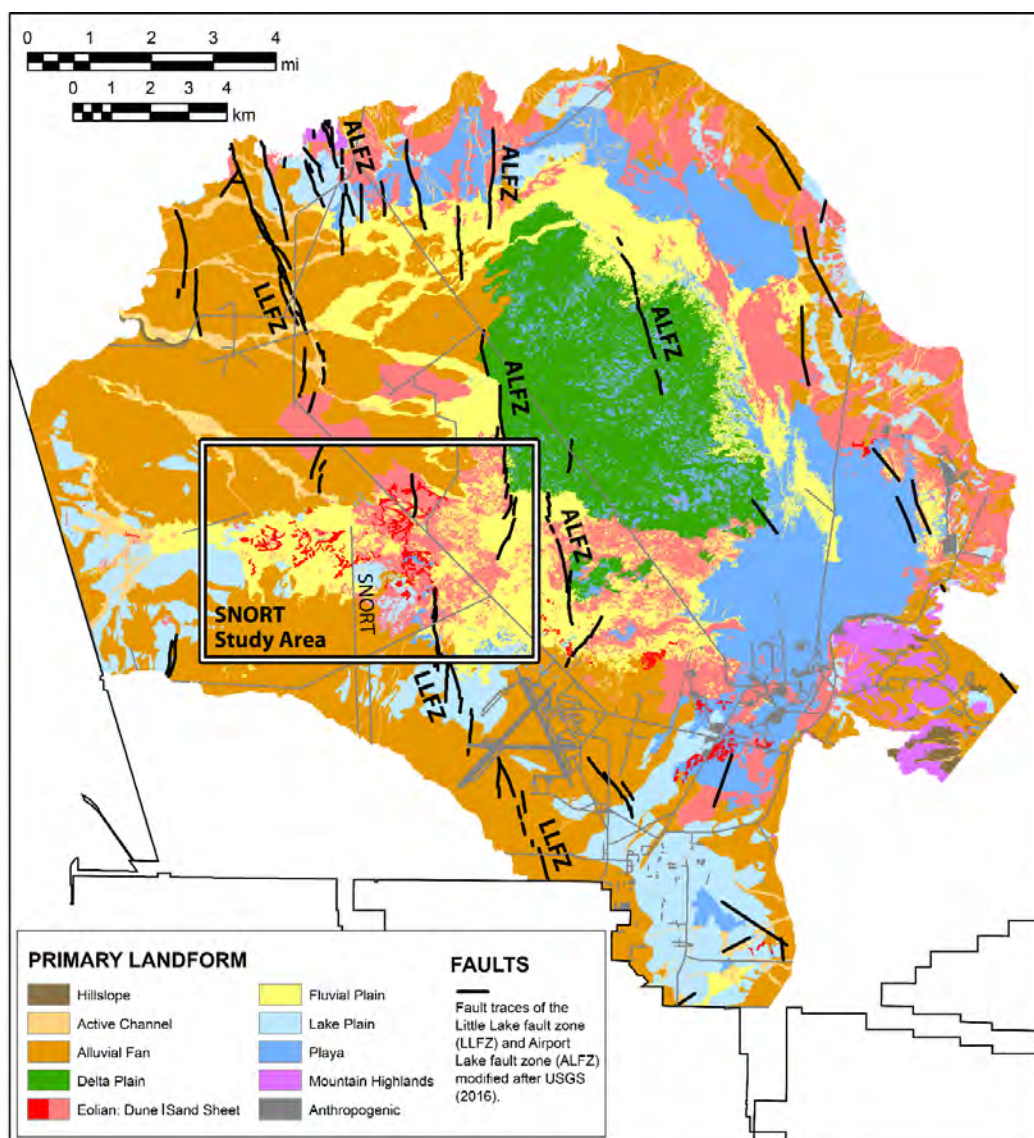


FIGURE 1-1. Map Showing Location of Supersonic Naval Ordnance Research Track (SNORT) Study Area in Relation to Geomorphic Map of China Lake Basin Below 700 m (2297 ft) Elevation Contour Within NAWC China Lake of Bacon *et al.* (2015) in Bullard *et al.* (2015).

The fault traces of the active Little Lake and Airport Lake fault zones from USGS (2016) are also shown in the area of the geomorphic map.

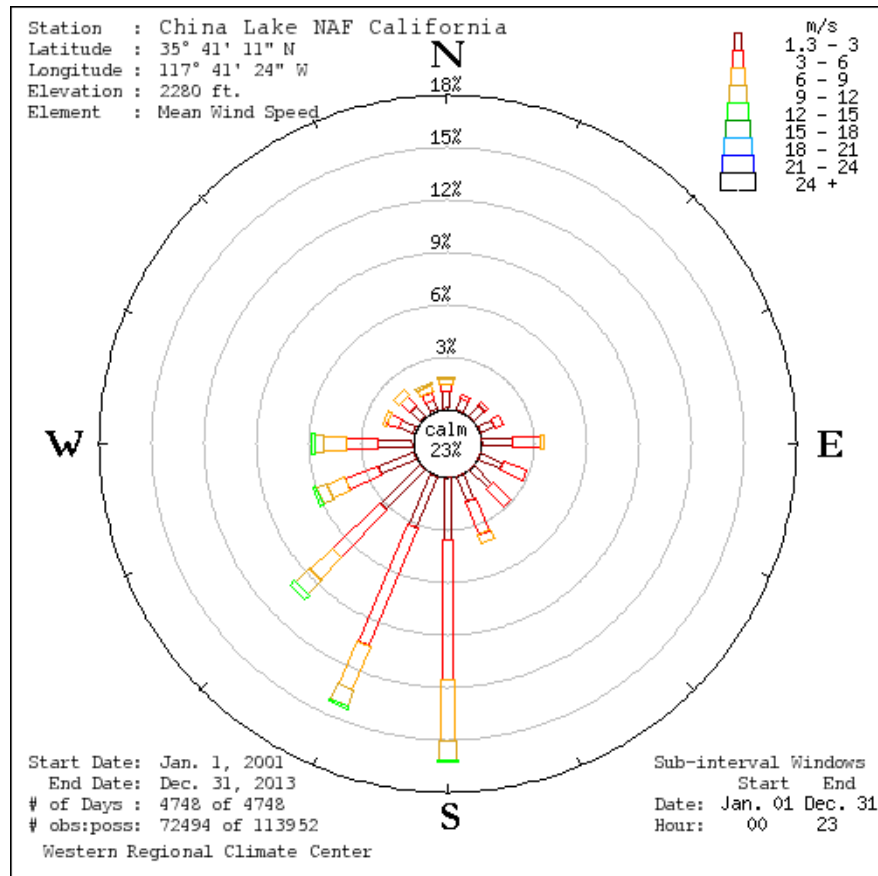


FIGURE 2-1. Annual Wind Rose Diagram for Period 2011–2013.
 Generated from CALCLIM data (accessed February 5, 2016).

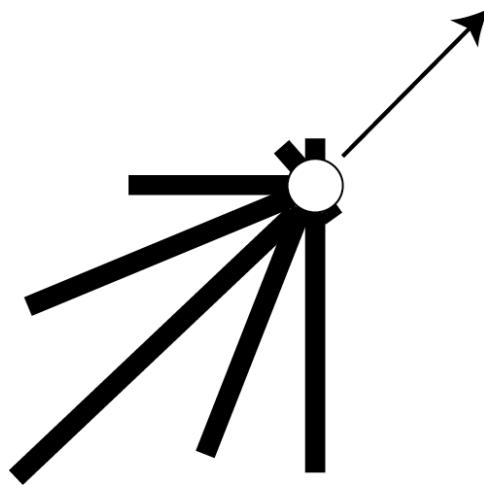


FIGURE 2-2. Rose Diagram Showing Annual Percentage of Sand Transport Potential
 From Different Directions. Arrow points in the direction of the resultant
 (vector sum) transport direction.

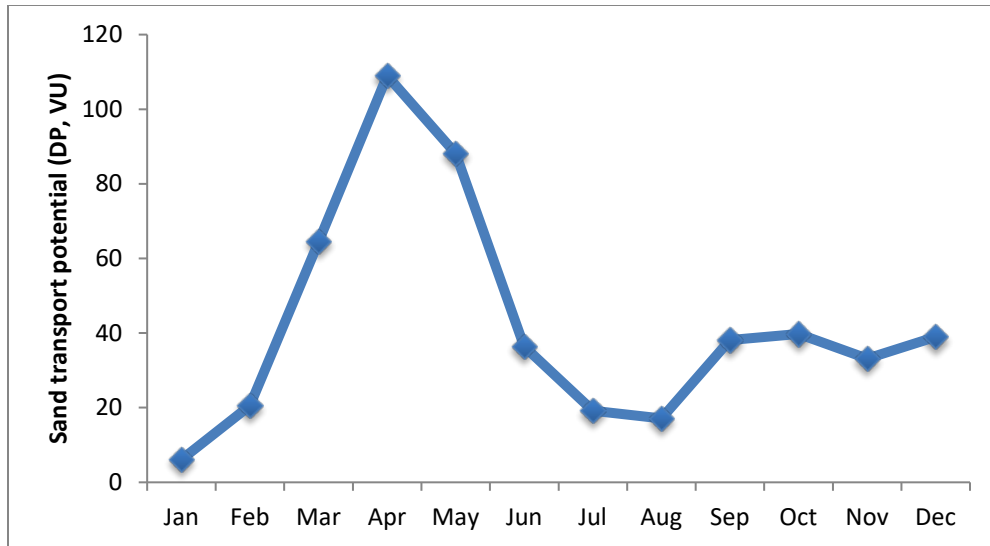


FIGURE 2-3. Plot Showing Seasonal Variation in Sand Transport Potential (DP) in 2010 as an Example Year.

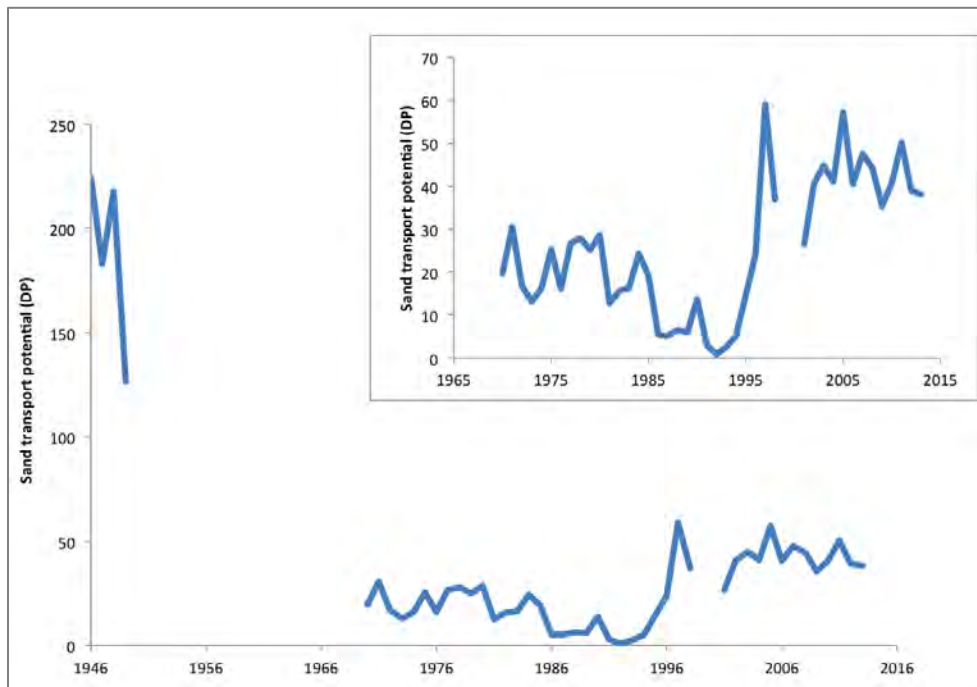


FIGURE 2-4. Plot Showing Time Series of Sand Transport Potential Over Period of Record. Inset shows period from 1970 to 2013.

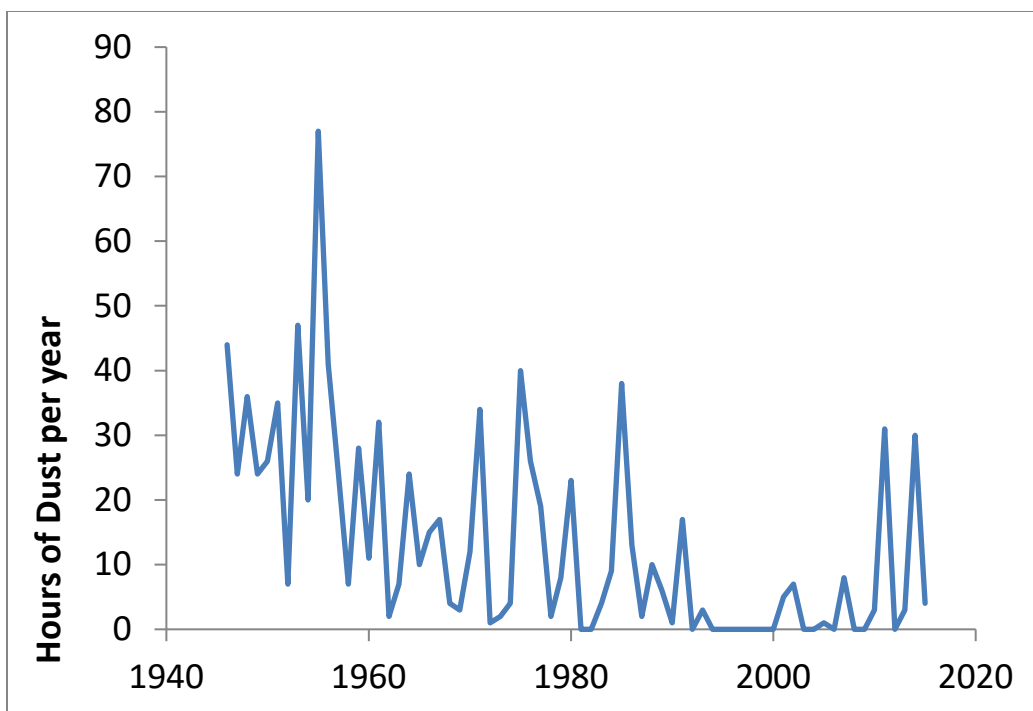


FIGURE 2-5. Plot showing Annual Frequency of Dust Events (Visibility < 11.3 km; 7 mi) From 1946 to 2015.

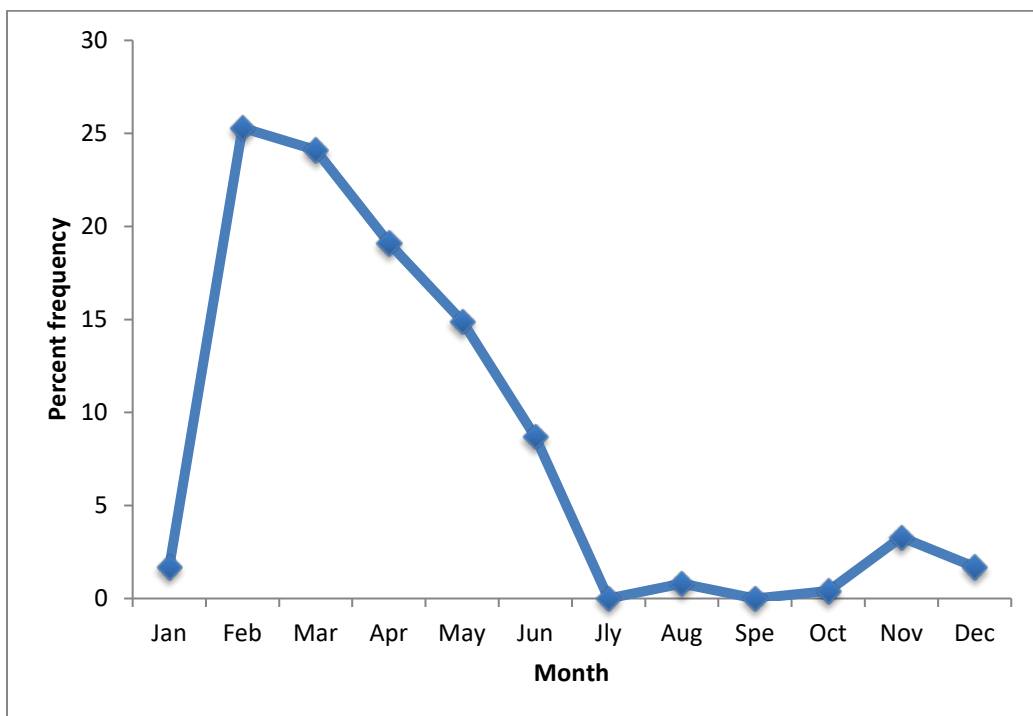


FIGURE 2-6. Plot Showing Percent Frequency of Dust Events per Month in 2010 as Example Year.

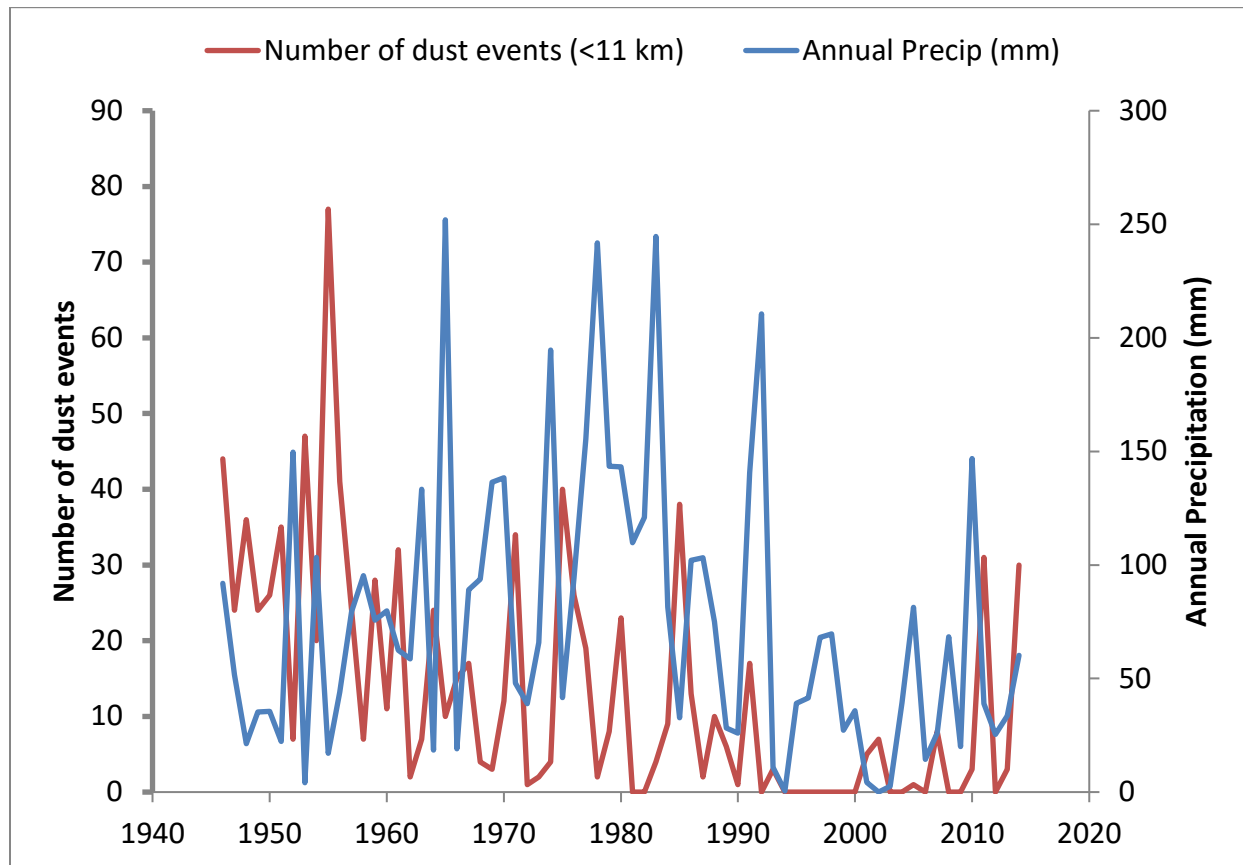


FIGURE 2-7. Plot showing Annual Frequency of Dust Events Compared To Annual Precipitation From 1946 to 2015.

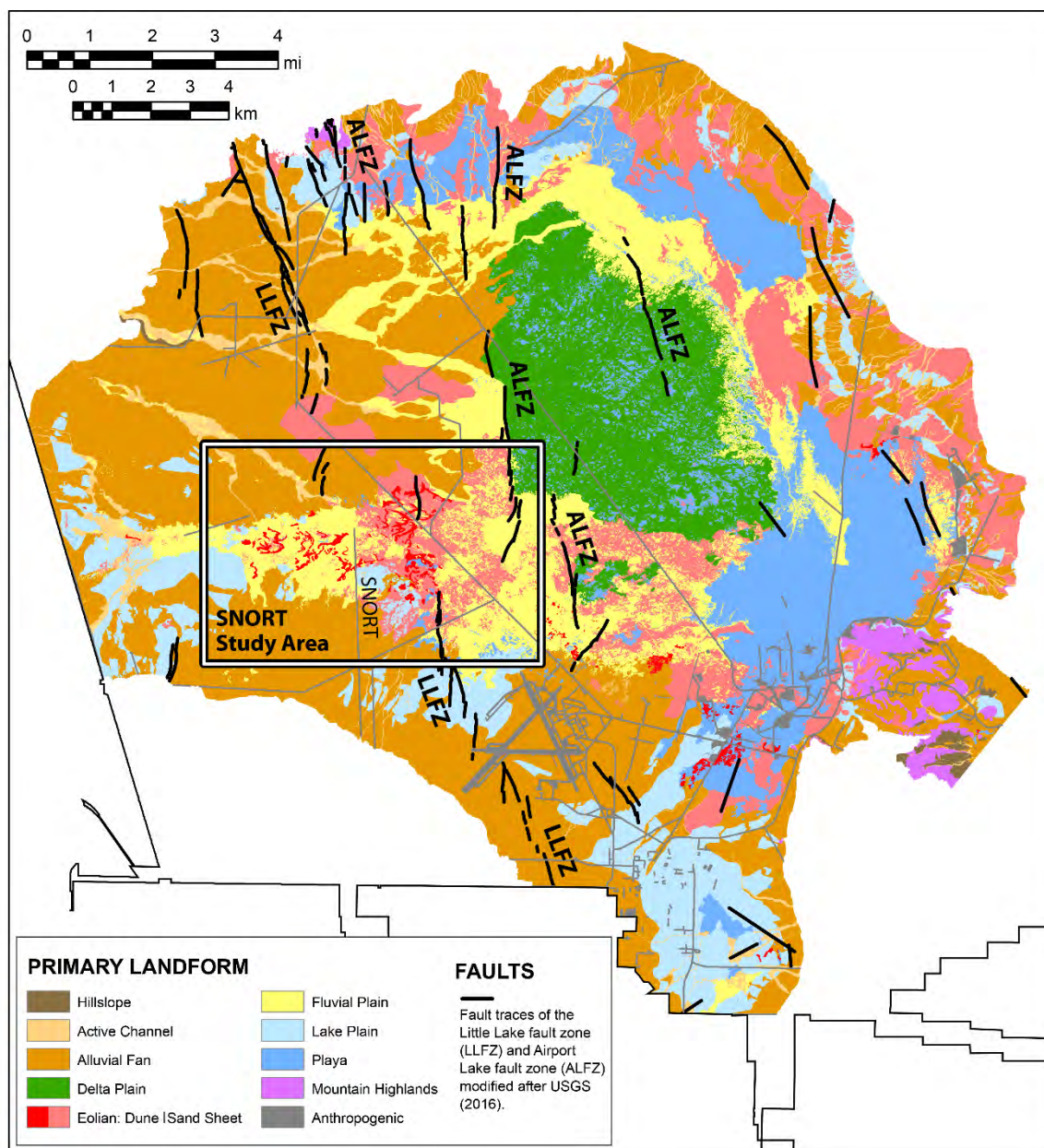


FIGURE 3-1. Map Showing Location of Supersonic Naval Ordnance Research Track (SNORT) Study Area in Relation to Geomorphic Map of China Lake Basin Below 700 m (2297 ft) Elevation Contour Within NAWS China Lake of Bacon et al. (2015) in Bullard et al. (2015).

The fault traces of the active Little Lake and Airport Lake fault zones from USGS (2016) are also shown in the area of the geomorphic map.

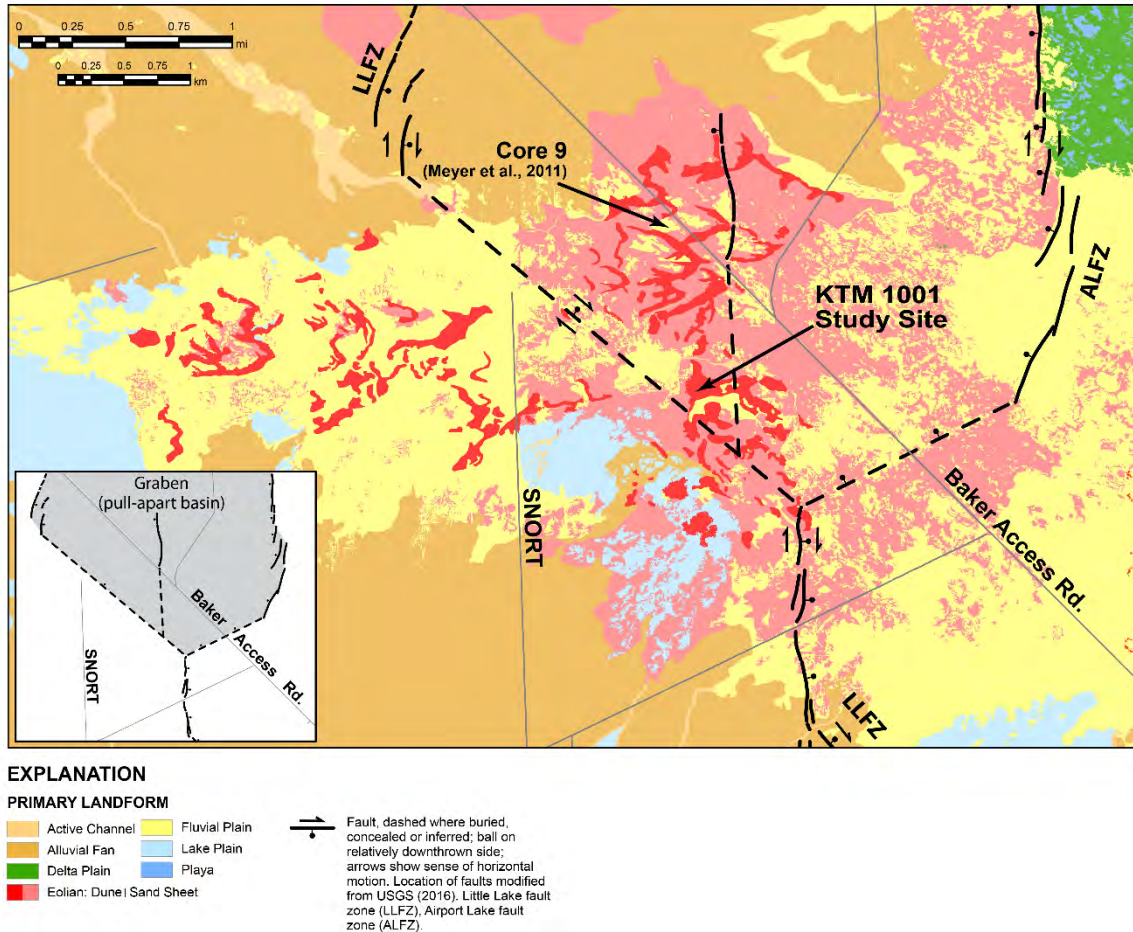


FIGURE 3-2. Geomorphic and Fault Map of SNORT Study Area Showing Northern ~1.9 km (1.2 mi) of SNORT Alignment Crossing a Well-Developed and Broad Axial Channel System (Yellow Shading).

The dominant landforms identified in the axial channel system include fluvial plains and vegetated sand dunes, as well as vegetated to barren sand sheets. The vegetated sand dunes have accumulated in two discrete areas that coincide with location of the Little Lake fault zone (LLFZ) and Airport Lake fault zone (ALFZ), and the axis of the broad fluvial plain west of SNORT. The location of the fault zones and related geometry forms a topographic low within a tectonic depression (gray area of inset) that influences the distribution and magnitude of stream and sand deposition in the area. Due to the lack of surface evidence, the locations of inferred faults are based on fault zone geometry. The locations of the KTM 1001 study site and Core 9 site of Meyer *et al.* (2011) are also shown.

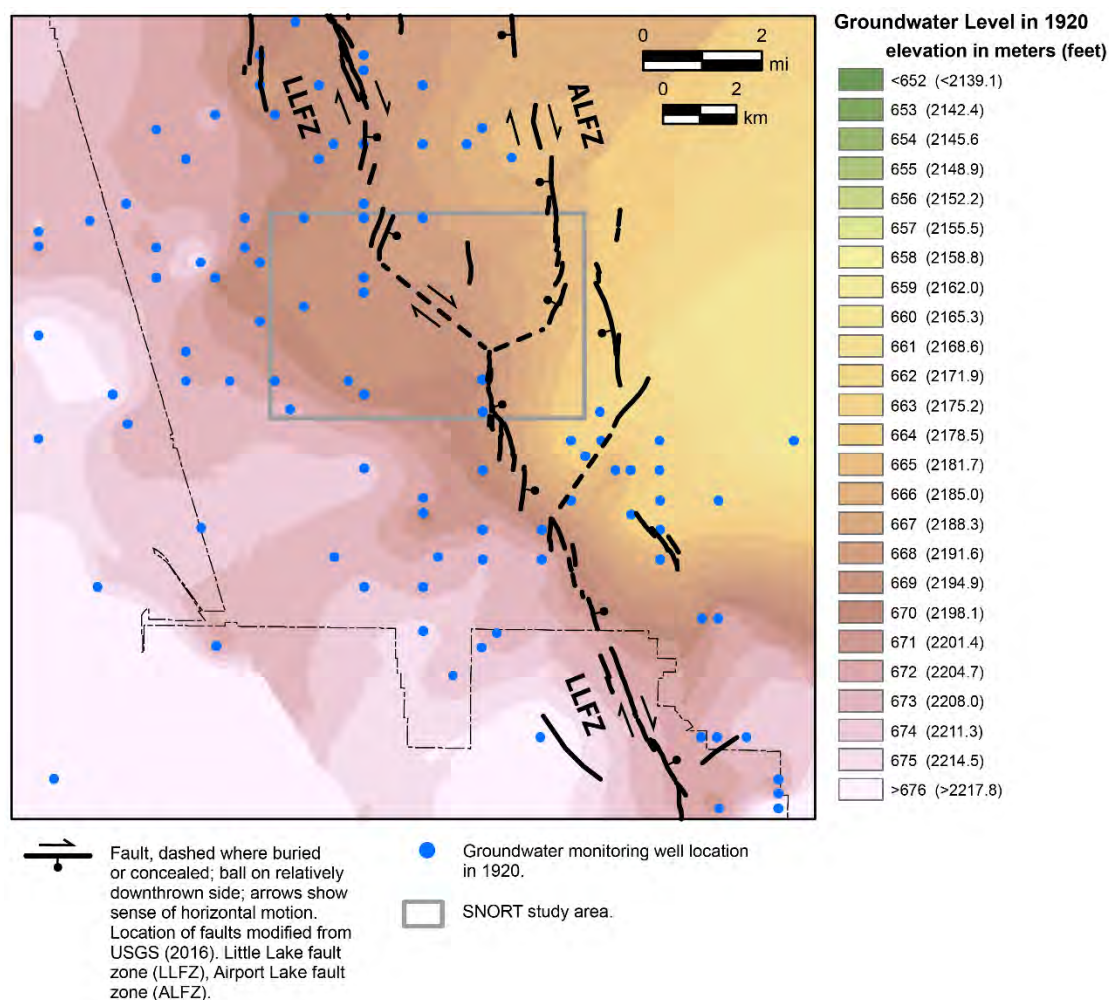


FIGURE 3-3. Map Showing Groundwater Level in 1920 and Active Fault Zones in Vicinity of Southwestern Sector of NAWS China Lake North Range.

The groundwater surface was constructed by interpolation of all available water-level data from groundwater monitoring wells in Indian Wells Valley at this time. The predevelopment groundwater level configuration appears to coincide with the location of active faults.

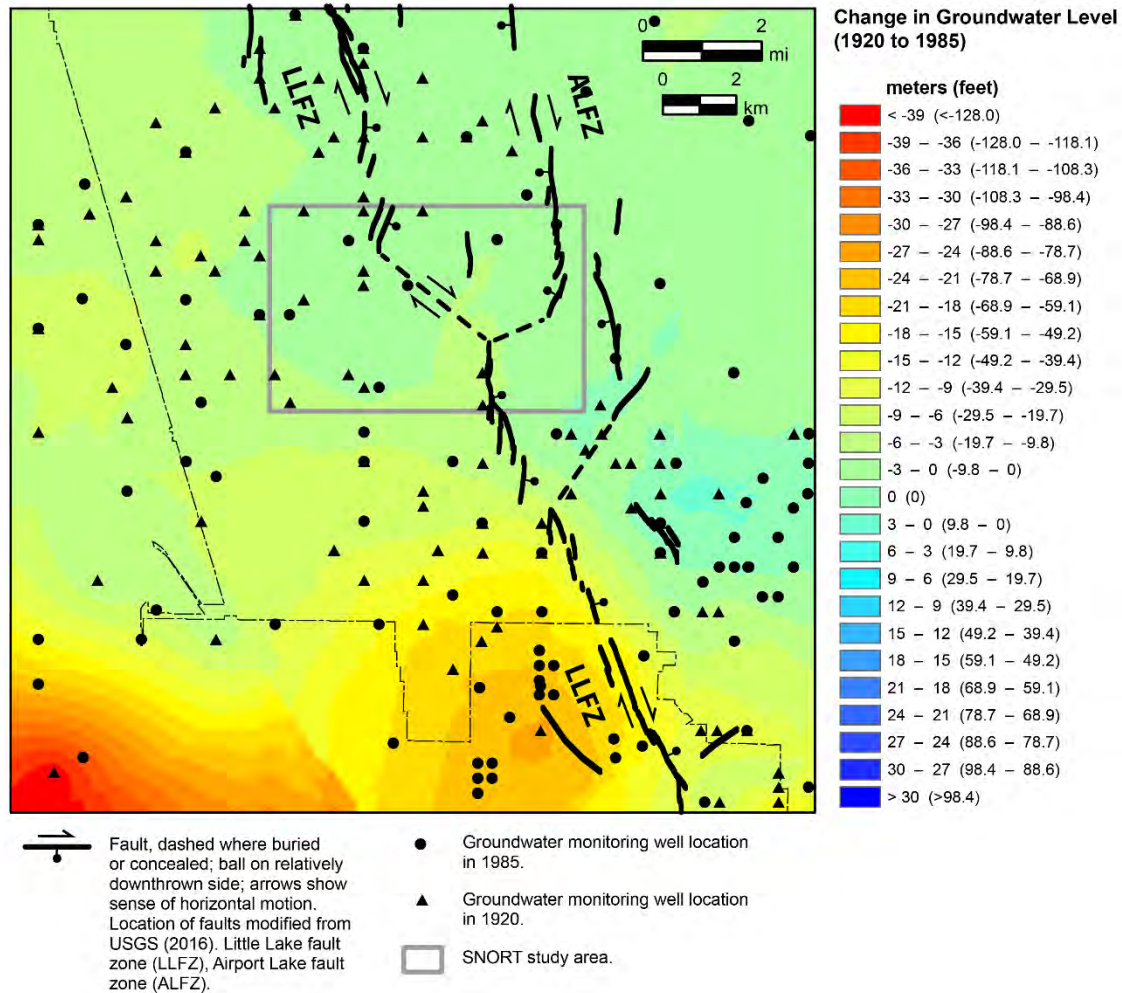


FIGURE 3-4. Map Showing Change in Groundwater Level Between 1920 and 1985 and Active Fault Zones in Vicinity of Southwestern Sector of NAWS China Lake North Range.

Similar to the absolute elevation of groundwater levels, the vertical change in groundwater levels reflect focused groundwater withdrawal in the form of a cone of depression outside of and within the boundary of the NAWS China Lake North Range. Besides the cone of depression, other localized areas also appear to be controlled by the location of branching sections of the active LLFZ and ALFZ. Of precautionary note, some modeling artifacts exist within the southwestern corner of the square-shaped interpolated surface outside of the boundary of the NAWS China Lake North Range due to limited well data biased toward high groundwater levels; therefore, caution should be made when interpreting groundwater levels in this area.

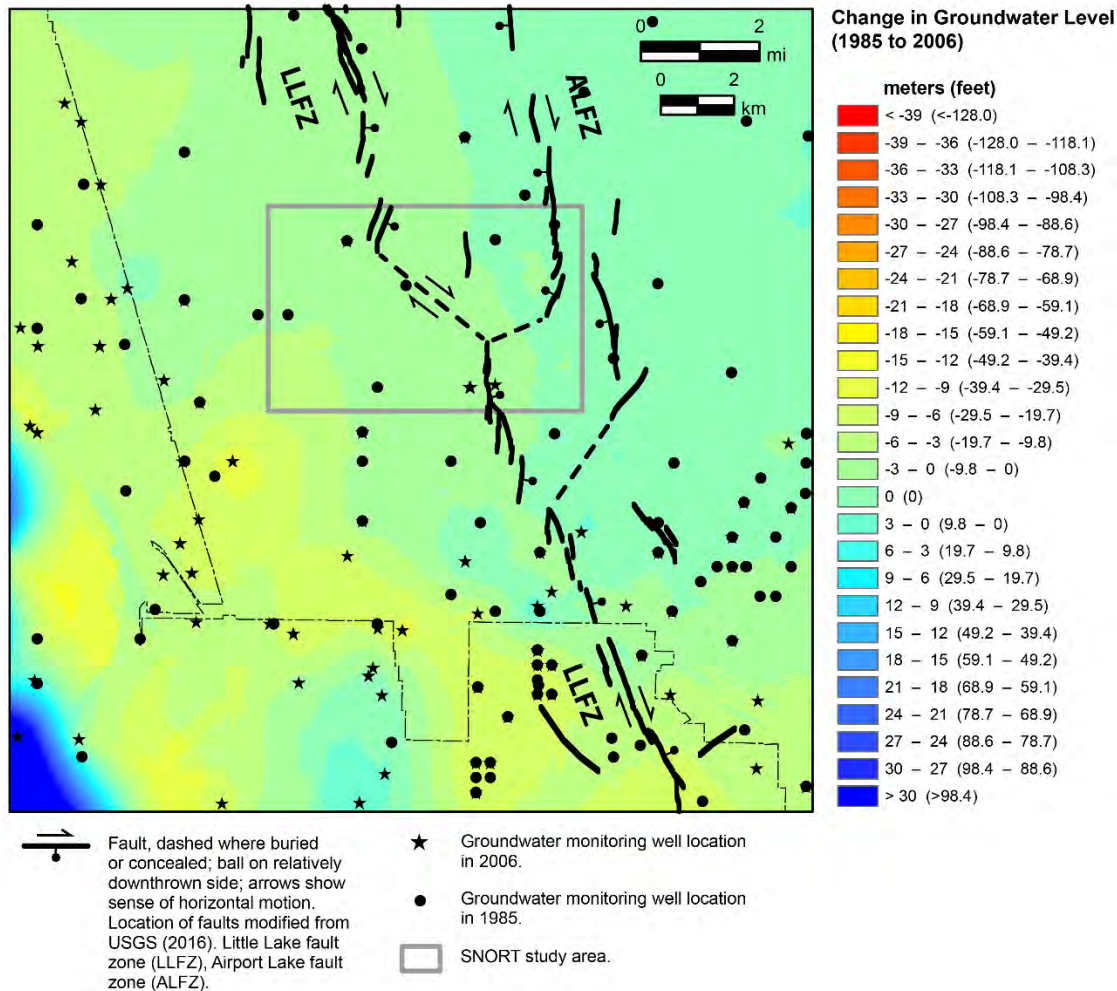


FIGURE 3-5. Map Showing Change in Groundwater Level Between 1985 and 2006 and Active Fault Zones in Vicinity of Southwestern Sector of NAWS China Lake North Range.

Similar to the absolute elevation of groundwater levels, the vertical change in groundwater levels reflect focused groundwater withdrawal in a narrow and elongated cone of depression outside of and within the boundary of the NAWS China Lake North Range. Besides the cone of depression, other localized areas also appear to be controlled by the location of branching sections of the active LLFZ and ALFZ. Of precautionary note, some modeling artifacts exist within the southwestern corner of the square-shaped interpolated surface outside of the boundary of the NAWS China Lake North Range due to limited well data biased toward high groundwater levels; therefore, caution should be made when interpreting groundwater levels in this area.

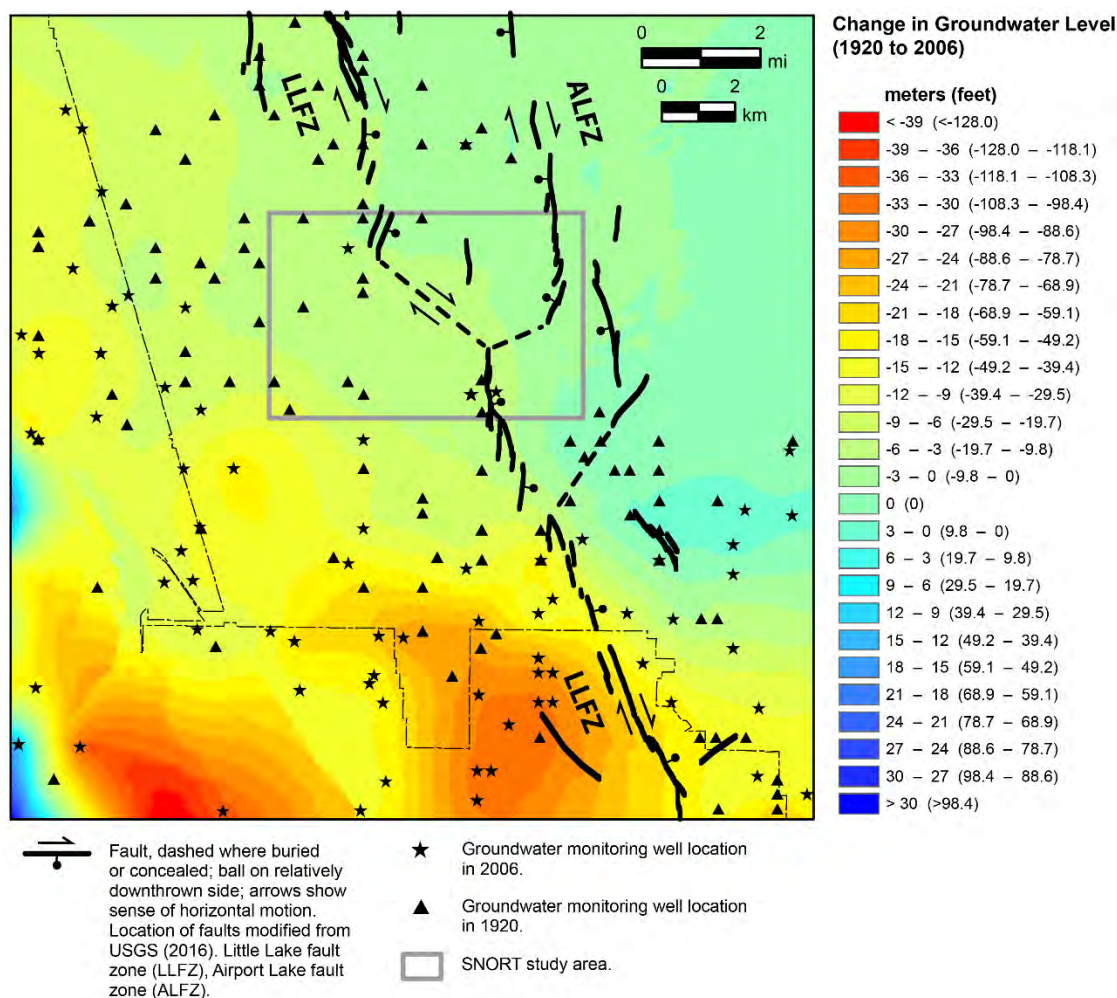


FIGURE 3-6. Map Showing Change in Groundwater Level Between 1920 and 2006 and Active Fault Zones in Vicinity of Southwestern Sector of NAWS China Lake North Range.

Similar to the absolute elevation of groundwater levels, the vertical change in groundwater levels reflect focused groundwater withdrawal in a narrow and elongated cone of depression outside of and within the boundary of the NAWS China Lake North Range. Besides the cone of depression, other localized areas also appear to be controlled by the location of branching sections of the active LLFZ and ALFZ. Of precautionary note, some modeling artifacts exist within the southwestern corner of the square-shaped interpolated surface outside of the boundary of the NAWS China Lake North Range due to limited well data biased toward high groundwater levels; therefore, caution should be made when interpreting groundwater levels in this area.

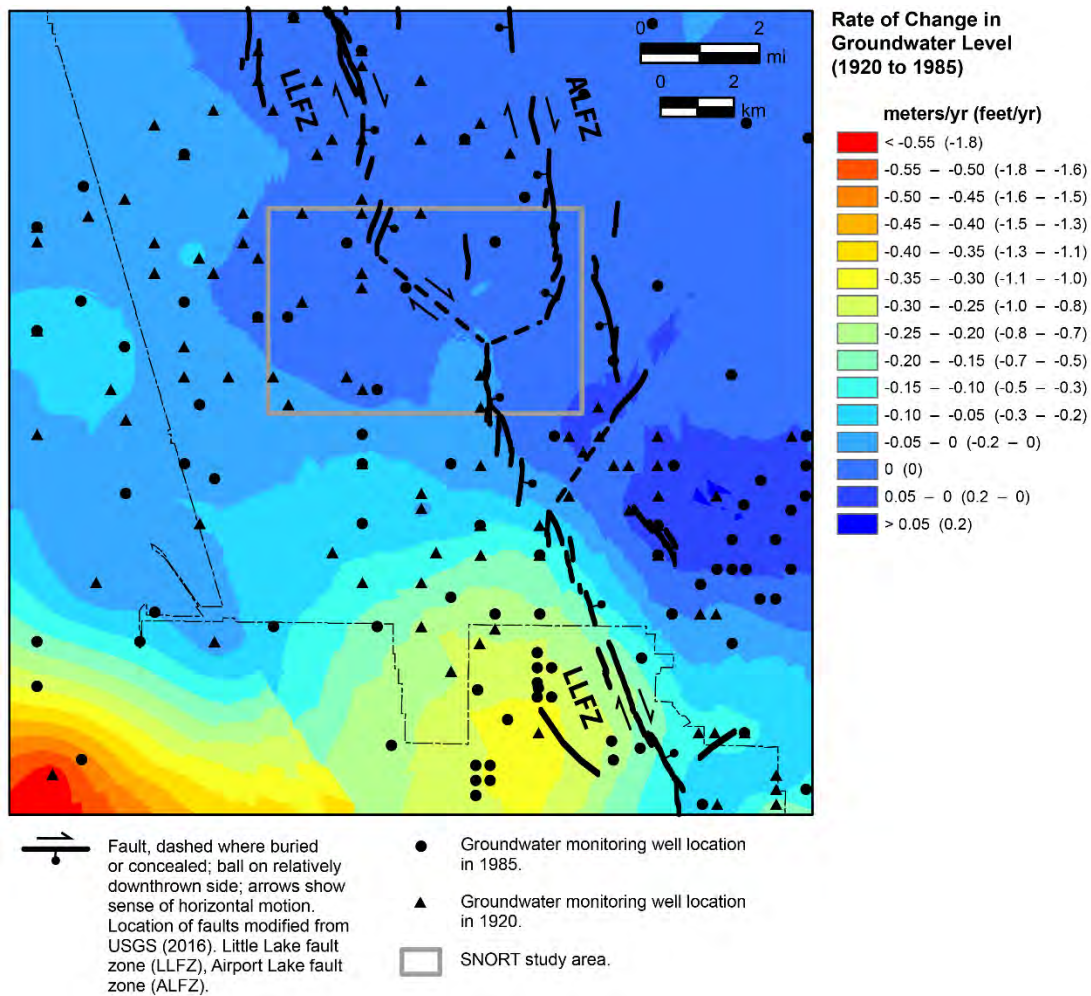


FIGURE 3-7. Map Showing Rate of Change in Groundwater Levels Between 1920 and 1985 and Active Fault Zones in Vicinity of Southwestern Sector of NAWS China Lake North Range.

The different rates show the location of focused groundwater withdrawal outside of and within the boundary of the NAWS China Lake North Range. The rate contours also appear to coincide closely with the location of branching sections of the active LLFZ and ALFZ. Of precautionary note, some modeling artifacts exist within the southwestern corner of the square-shaped interpolated surface outside of the boundary of the NAWS China Lake North Range due to limited well data biased toward high groundwater levels; therefore, caution should be made when interpreting groundwater levels in this area.

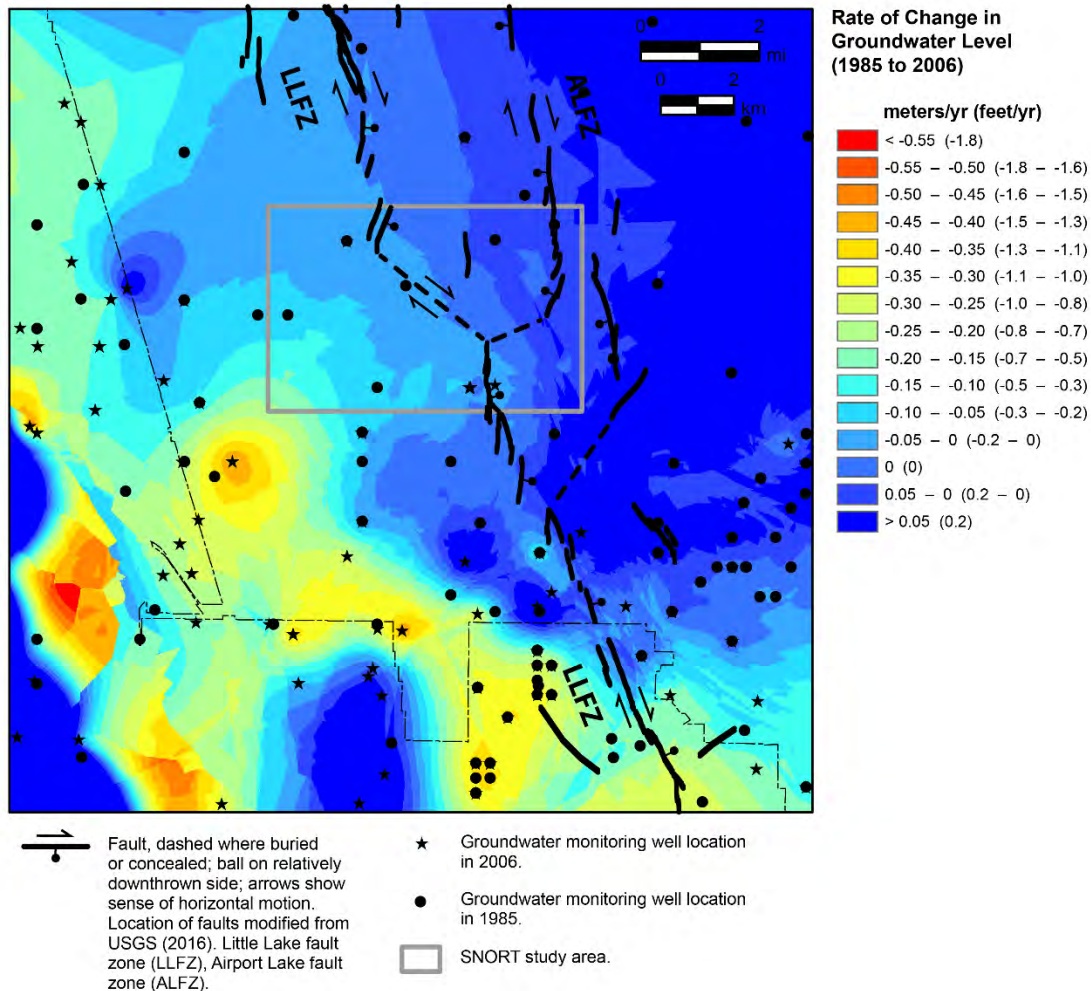


FIGURE 3-8. Map Showing Rate of Change in Groundwater Levels Between 1985 and 2006 and Active Fault Zones in Vicinity of Southwestern Sector of NAWS China Lake North Range.

The different rates show the location of focused groundwater withdrawal outside of and within the boundary of the NAWS China Lake North Range. The rate contours also appear to coincide closely with the location of branching sections of the active LLFZ and ALFZ. Of precautionary note, some modeling artifacts exist within the southwestern corner of the square-shaped interpolated surface outside of the boundary of the NAWS China Lake North Range due to limited well data biased toward high groundwater levels; therefore, caution should be made when interpreting groundwater levels in this area.

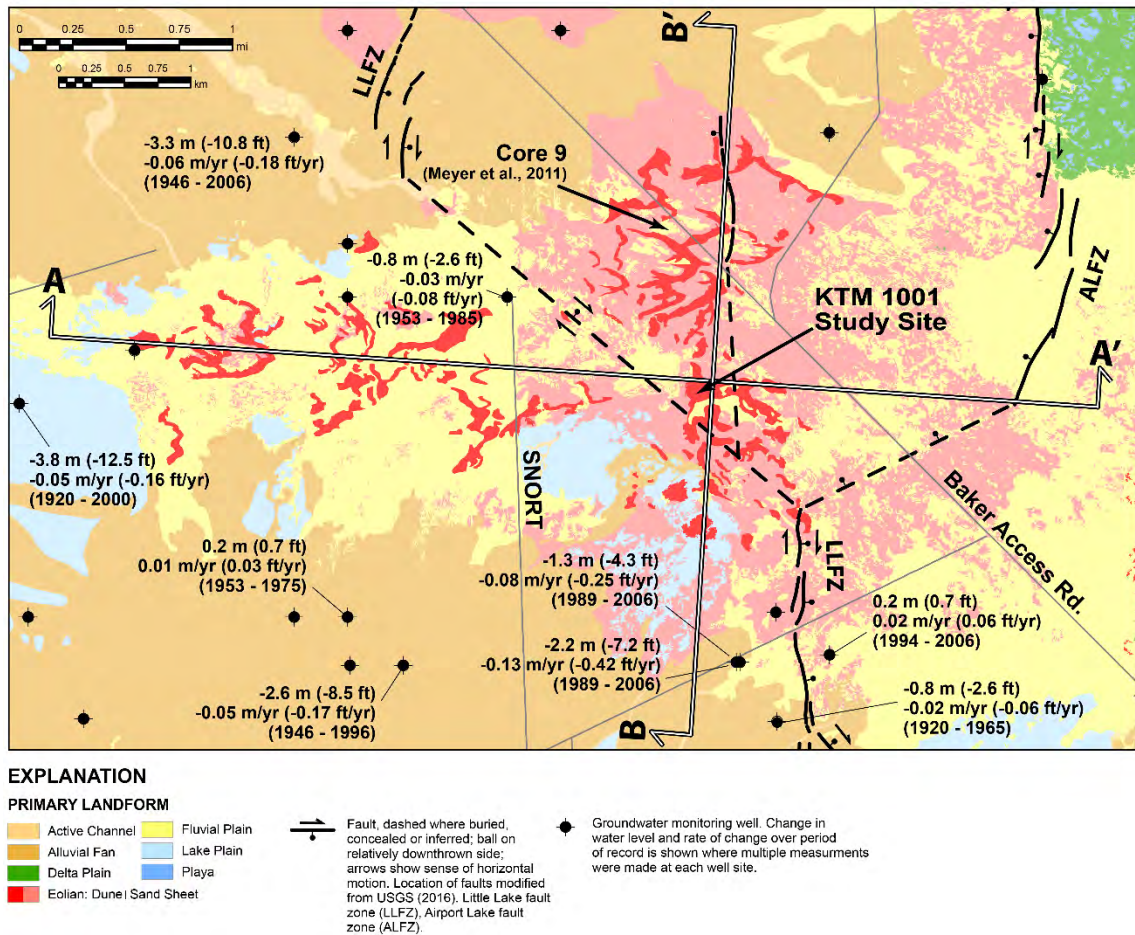


FIGURE 3-9. Geomorphic and Fault Map of SNORT study Area Showing Location of Transects A-A' and B-B' and Groundwater Monitoring Wells.

The change in water and rate of change over specific periods are also shown in relation to the active LLFZ and ALFZ. The rate of change in water levels of wells that are within 200 m (660 ft) of the LLFZ tend to have values that are nearly half of what is measured in wells that are located greater than 440 m (0.27 mi) west of the LLFZ.

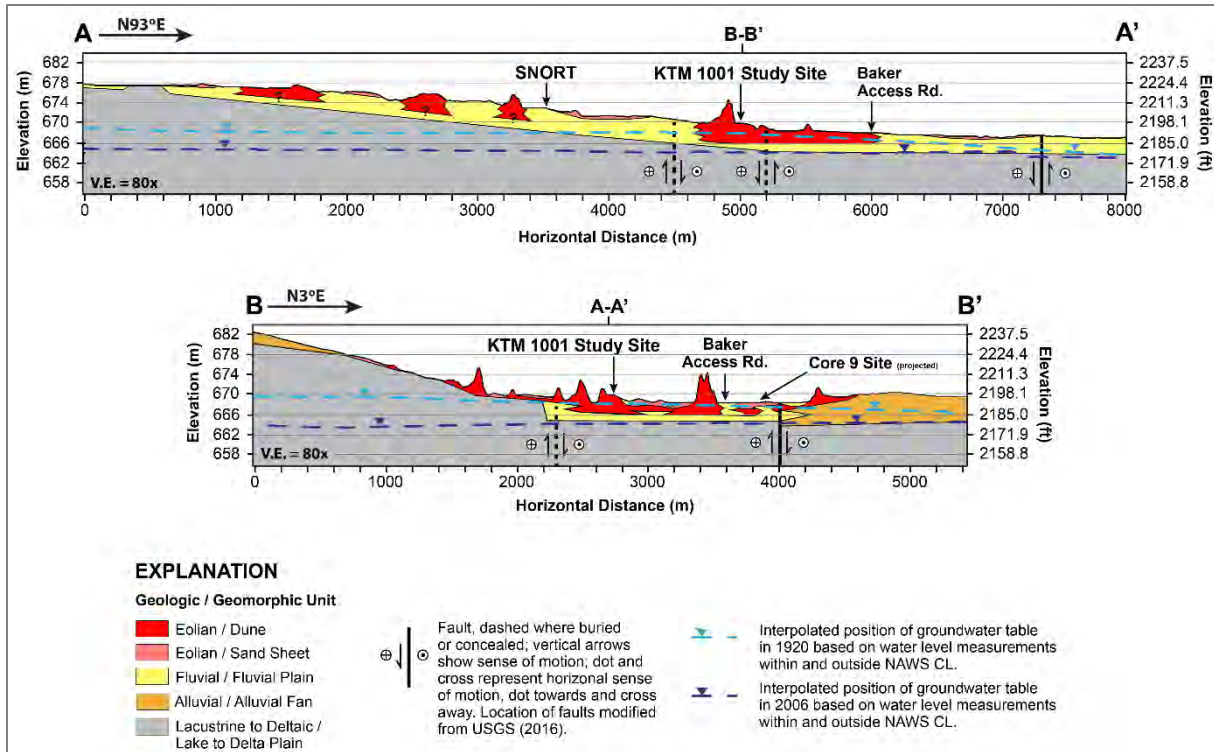


FIGURE 3-10. Geologic Cross Sections Oriented on West-East Transect (A-A') and South-North Transect (B-B) Across SNORT Study Area.

The subsurface geology shown on the cross sections is based on observed stratigraphic exposures at the KTM 1001 trench site, descriptions from a nearby ~10.7-m (35.1-ft) deep sediment core (Core 9 of Meyer *et al.*, 2011), inferences from mapped geomorphology, and location of faults modified after USGS (2016). Interpolated groundwater levels in the area for the years 1920 and 2006 are shown. The locations of the SNORT alignment, the KTM 1001 study site, Core 9 site, and Baker Access Road are also shown.



FIGURE 4-1. Photograph Showing KTM 1001 Trench Site, View to East.

Pale colored material consists of lacustrine to deltaic deposits underlying fluvial plain deposits, which are in turn overlain by eolian deposits.



FIGURE 4-2. Location of Stratigraphic Sections at KTM 1001 Trench Site Referred to in Text.

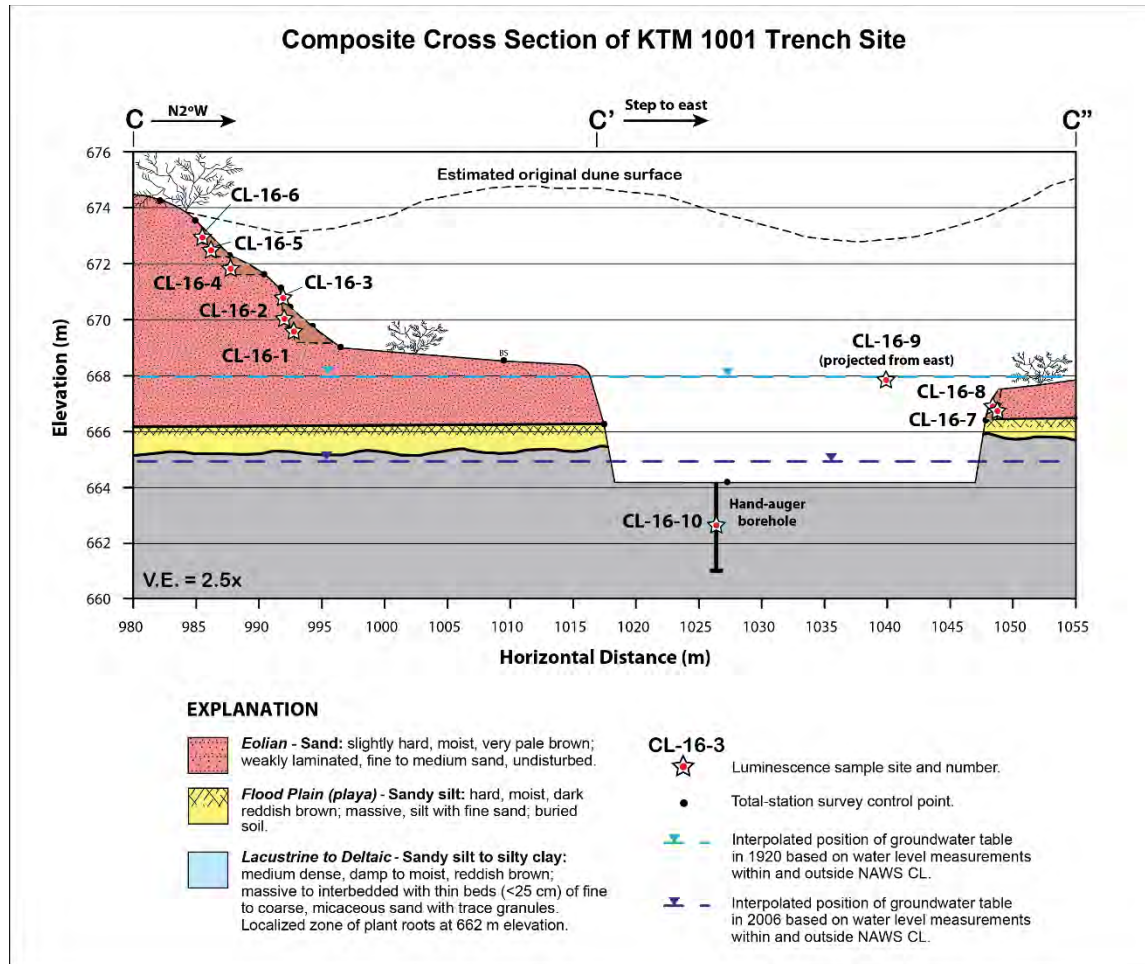


FIGURE 4-3. Composite Geologic Cross Section of KTM 1001 Trench Site Showing Vertical Position of Eolian, Flood Plain (Playa), and Lacustrine to Deltaic Depositional Units Identified and Described at Site.

The trench was excavated through a well-developed vegetated sand dune as a borrow source for the construction of KTM 1001. The location and numbers of samples taken for IRSL-age dating are shown. The location of hand-auger borehole placed at the bottom of the trench is also shown, as are the interpolated surfaces of the local groundwater table in 1920 and 2006.



FIGURE 4-4. Photograph Showing Benches Excavated into Trench Wall and IRSL Sample (CL-16-1 to CL-16-6) Locations at KTM West Stratigraphic Section Locality.



FIGURE 4-5. Photograph of KTM East (North) Stratigraphic Section Location Showing Eolian Deposits and IRSL Sample (CL-16-8) Location.



FIGURE 4-6. Photograph of KTM East (South) Stratigraphic Section Location Showing Extensive Bioturbation Within Upper 0.55 m (1.8 ft) of Exposure and IRSL Sample (CL-16-9) Location Within Eolian Sandy Sediments.

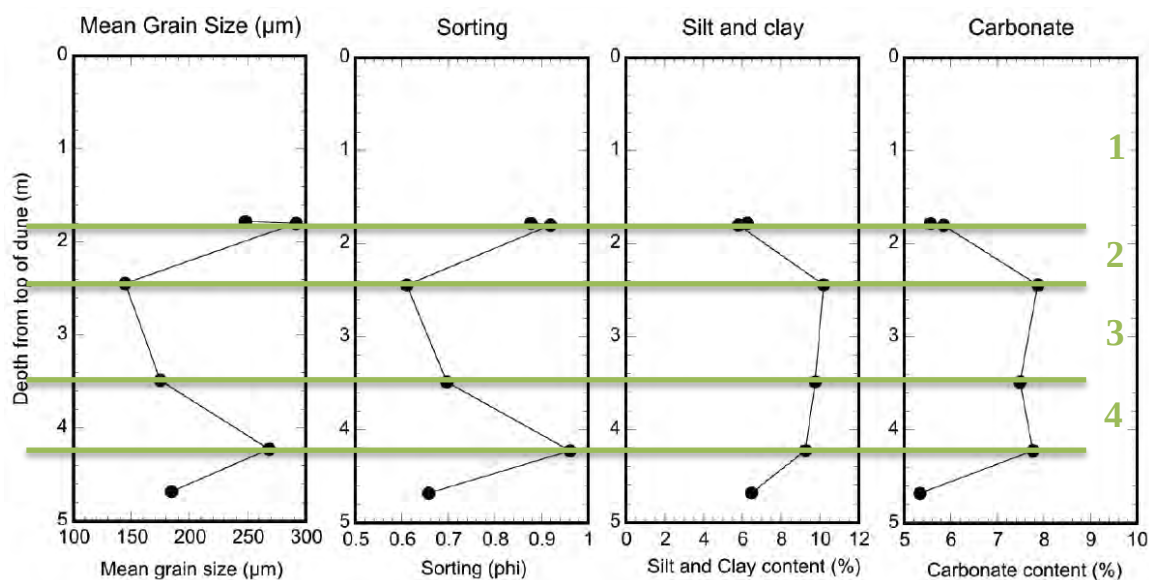


FIGURE 4-7. Depth Profiles of Eolian Deposits at KTM East (North) Locality Showing a Variety of Sedimentologic and Pedologic (i.e., soil) Properties used to Distinguish Four Subtle Depositional Units Within Upper Dune Stratigraphy of KTM 1001 Study Site.

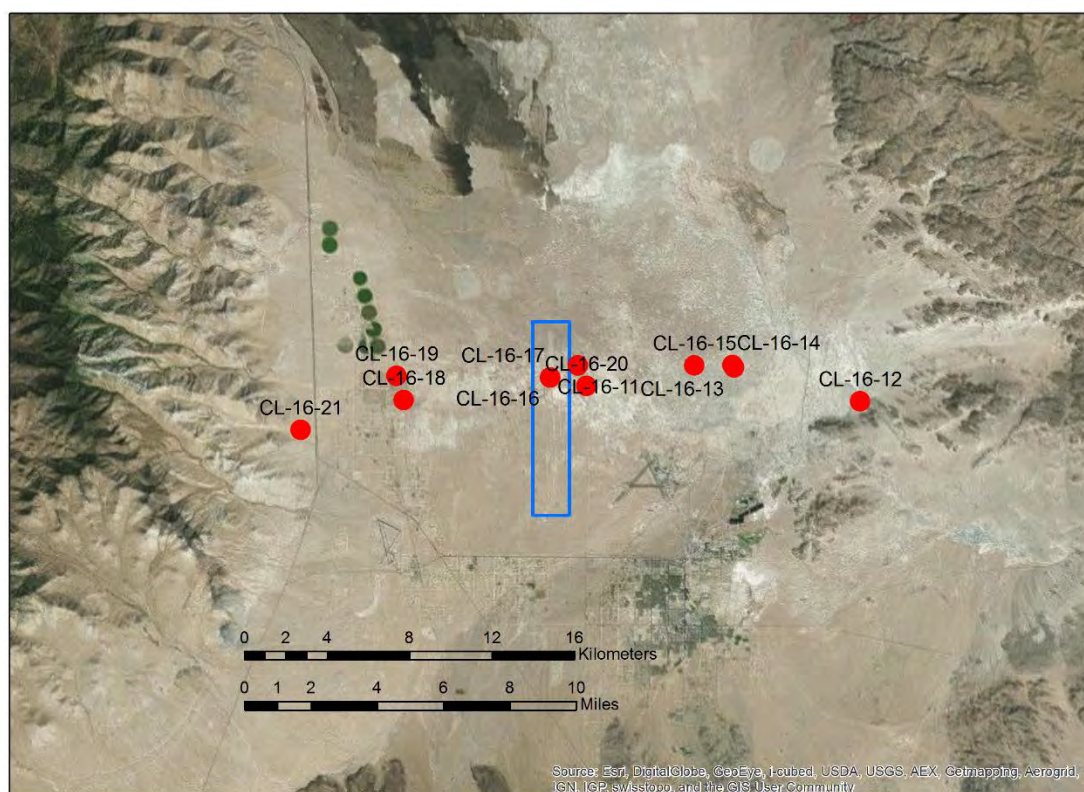


FIGURE 5-1. Location of Samples (Blue Box Indicates Area of SNORT Facility).

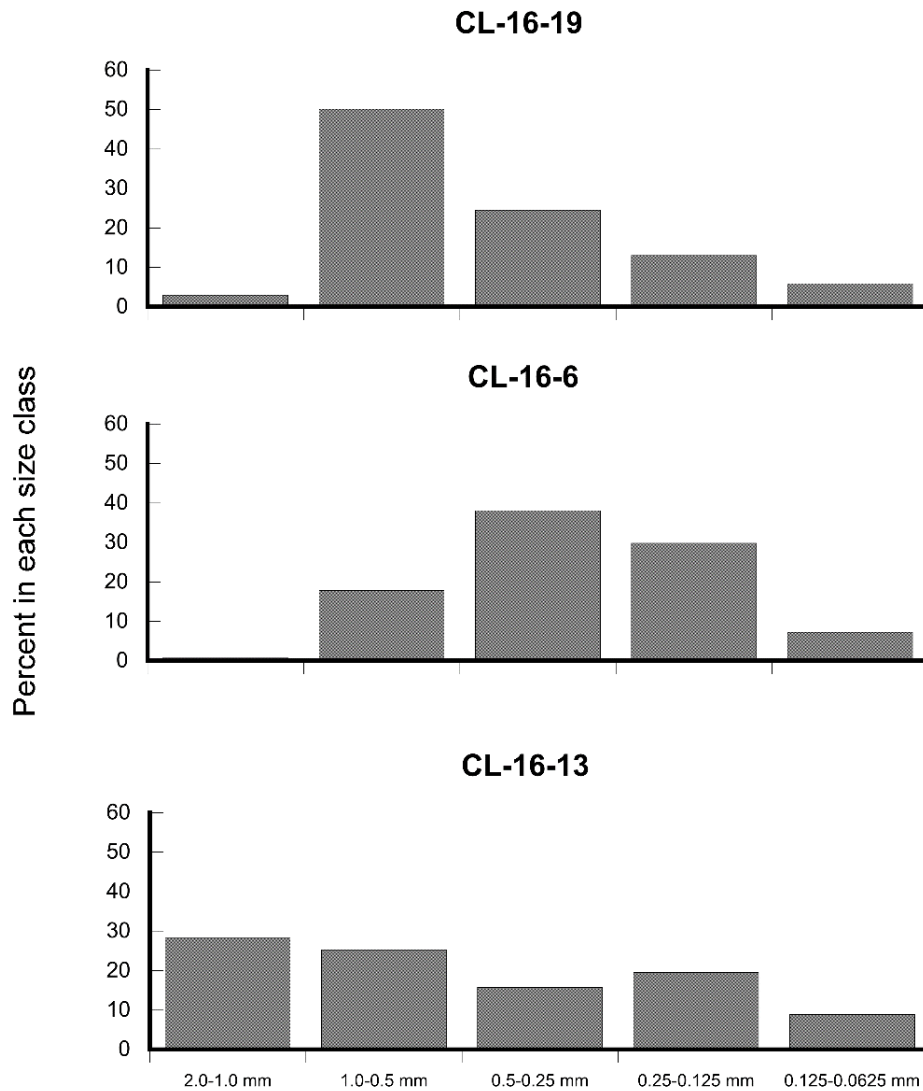


FIGURE 5-2. Representative Sand-Size Particle Size Distributions.

CL-16-19—West Boundary Fence Line Dune;

CL-16-6—Vegetation stabilized dune east of SNORT;

CL-16-13—Kennedy Stands dunes

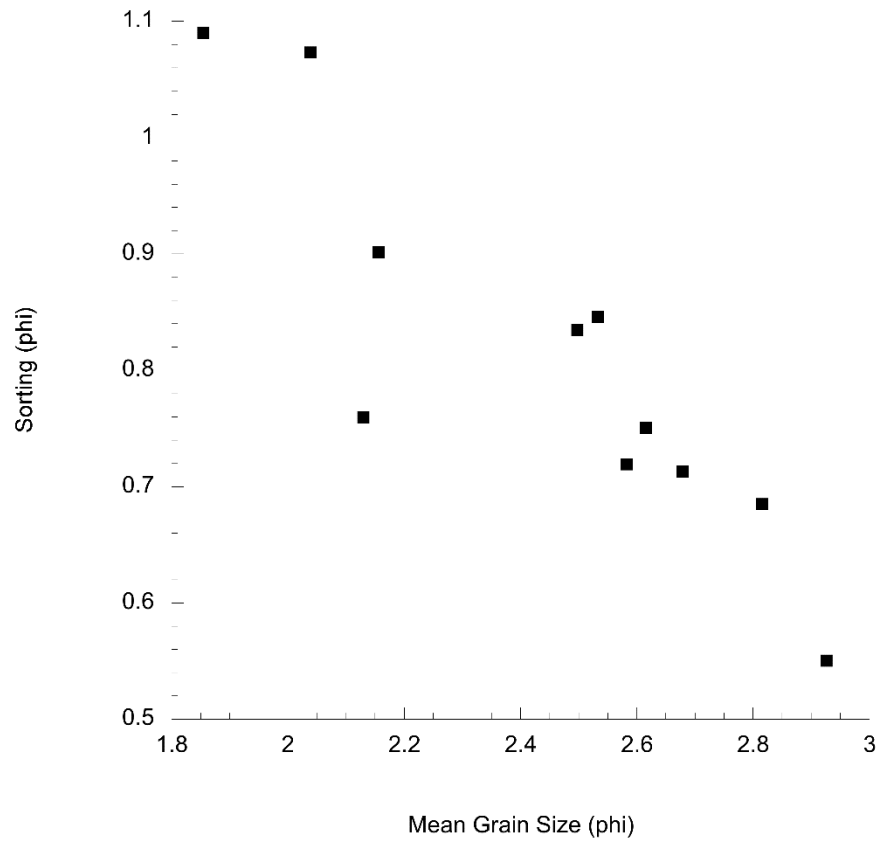


FIGURE 5-3. Relationship Between Mean Grain Size and Sorting for China Lake Surface Sand Samples.

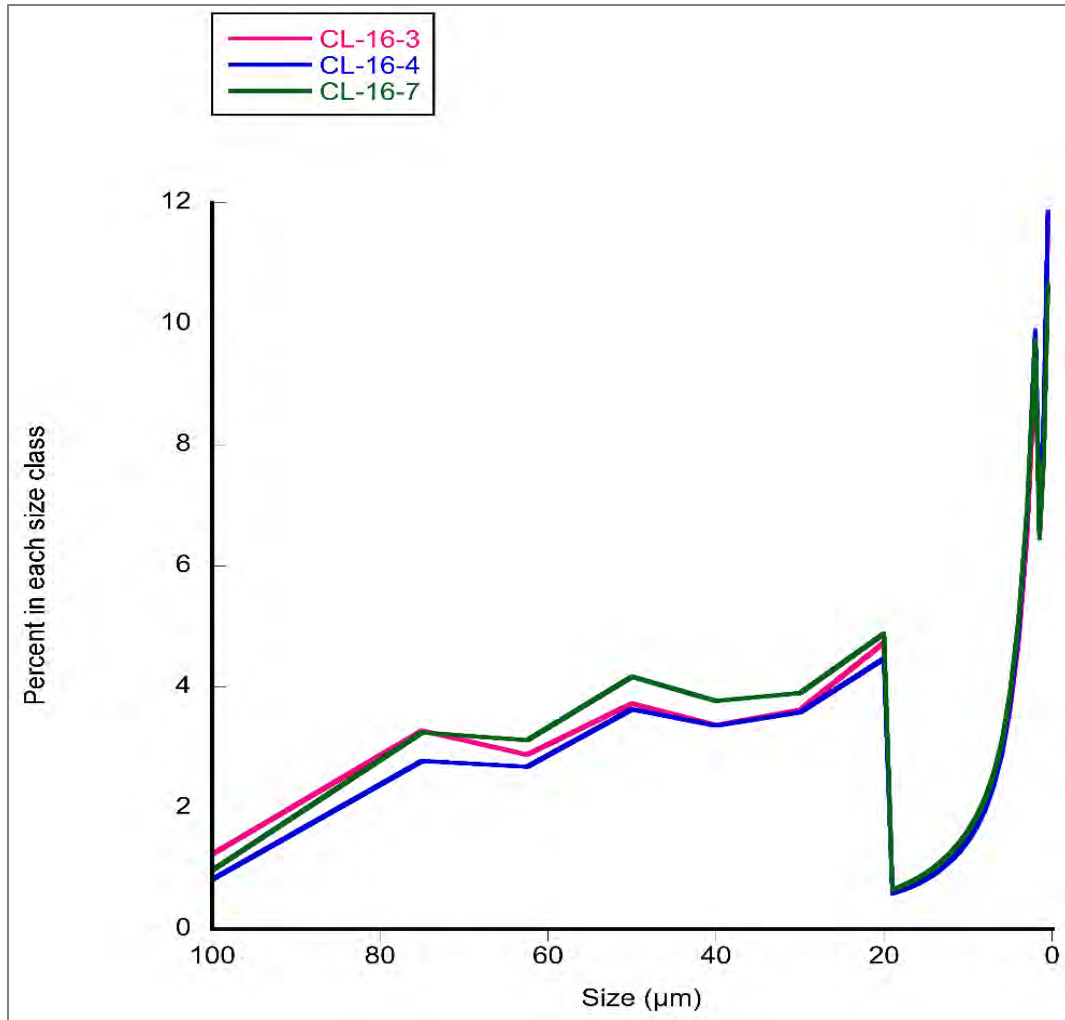


FIGURE 5-4. Laser Particle Size Analysis of <100μm Fraction of Selected Samples From KTM 1001 Trench.

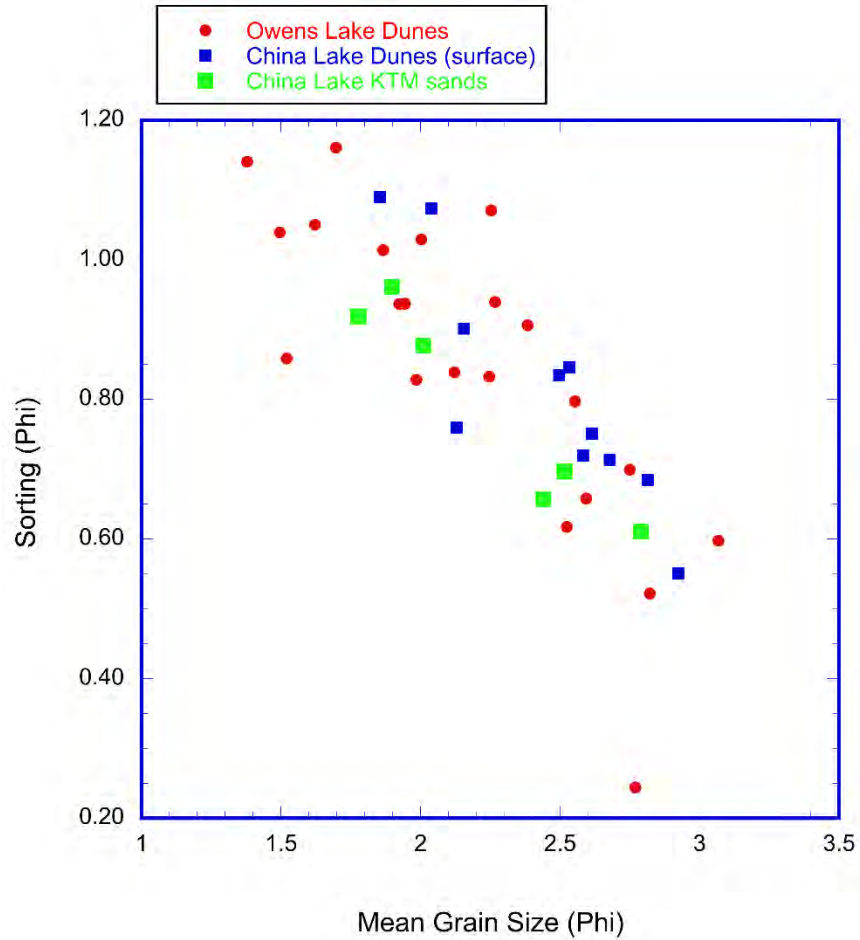


FIGURE 5-5. Comparison of Mean Grain Size and Sorting Between China Lake Sands and Sand Dunes in Owens Lake Basin.

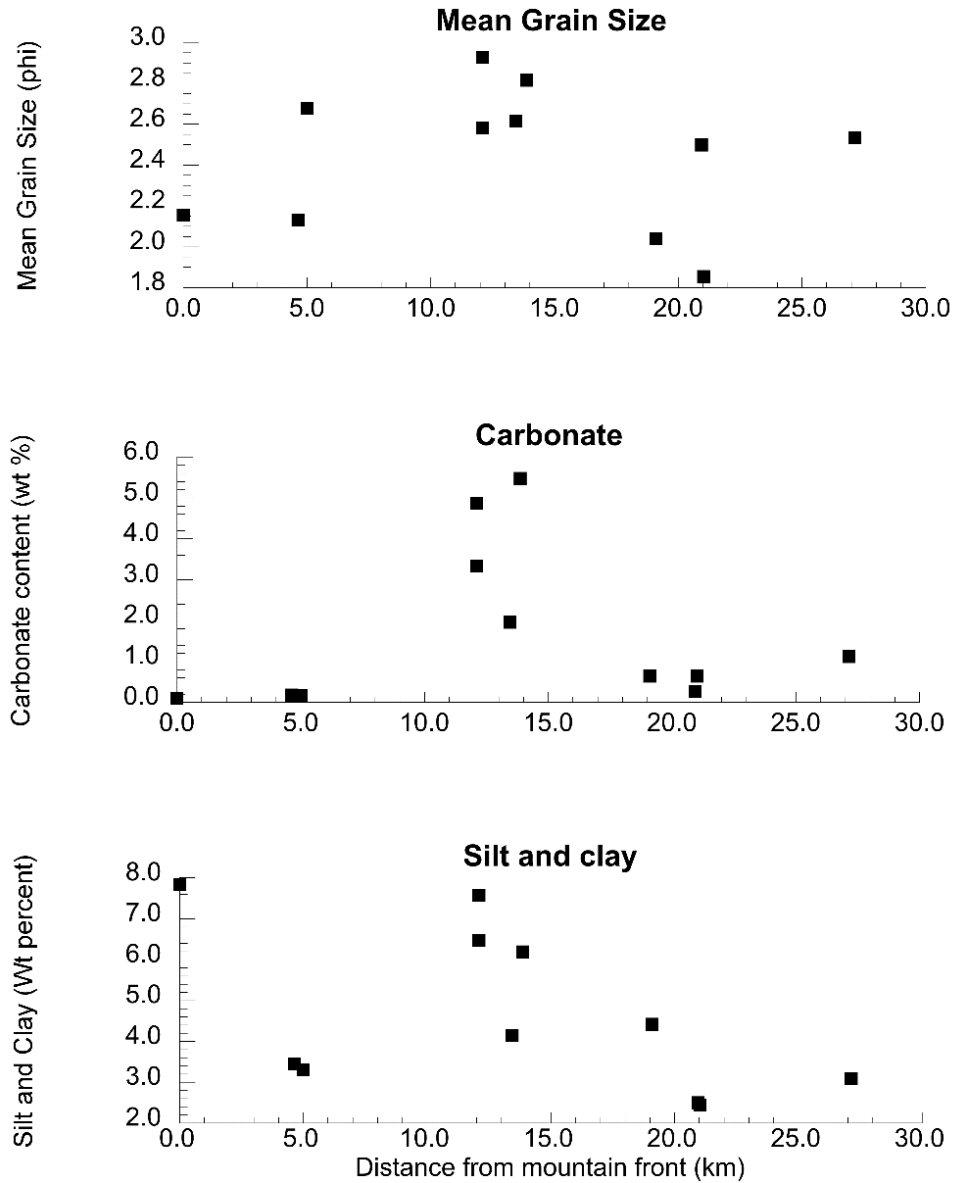


FIGURE 5-6. Change in surface Sand Grain Size, Carbonate Content, and Silt and Clay Content With Distance East From Sierra Nevada Mountain Front. SNORT lies at 12-14 km.

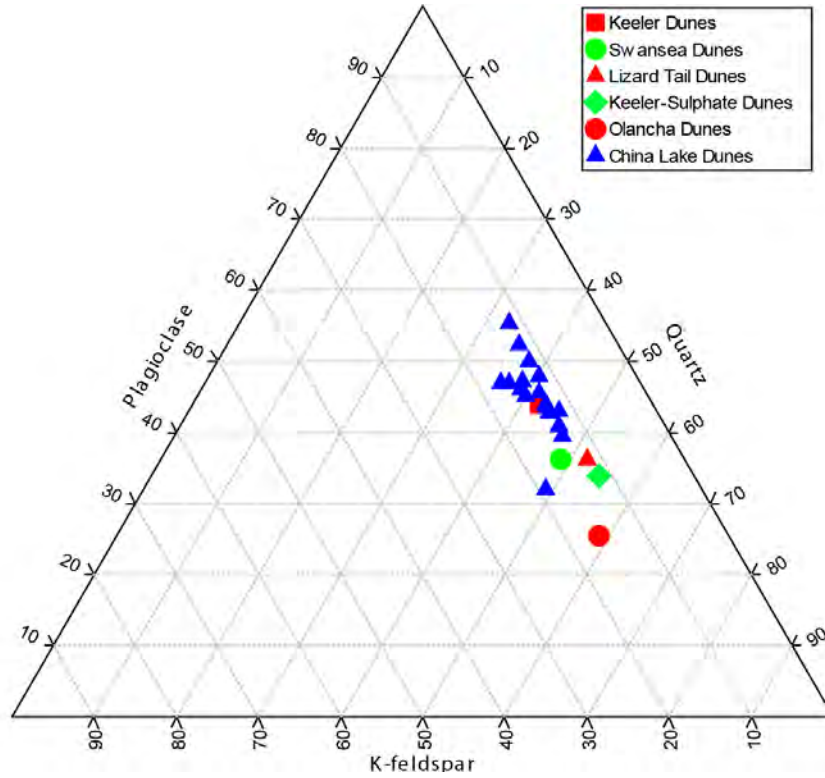


FIGURE 5-7. Ternary Diagram of Mineral Composition of China Lake Sands in Comparison to Sand Dunes From Owens Lake.

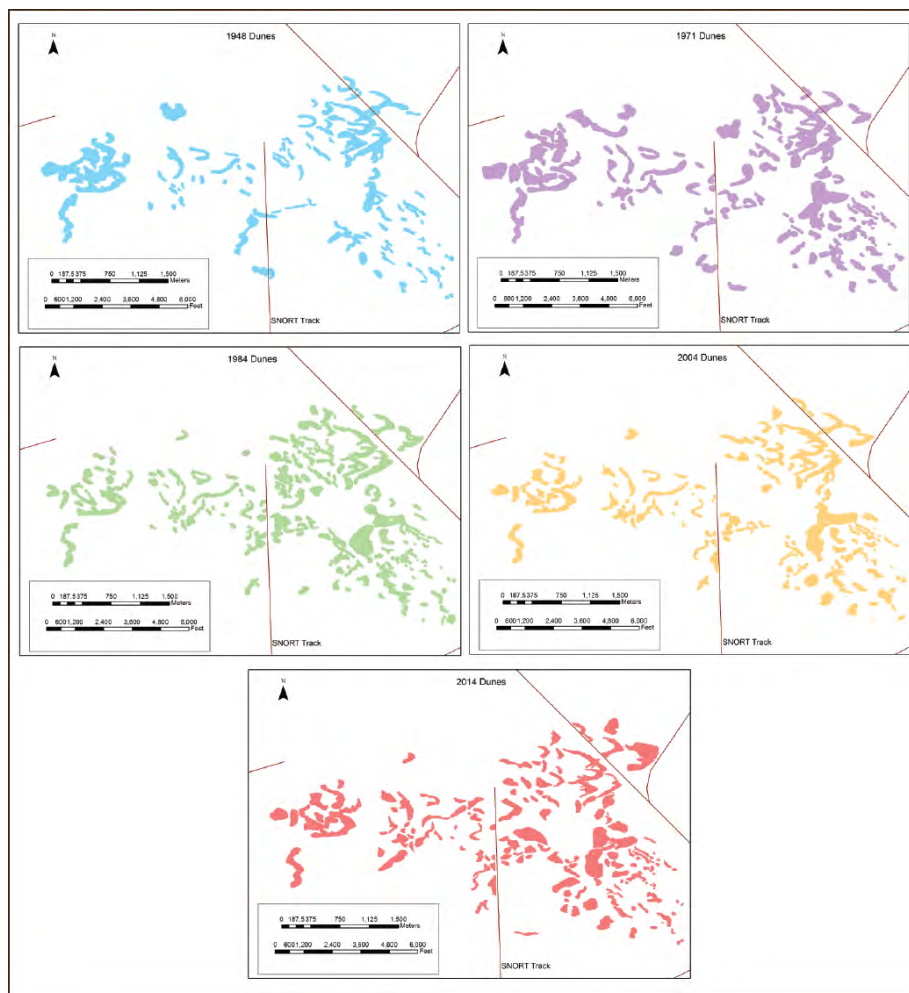


FIGURE 6-1. Maps of Dune Features for Years 1948, 1971, 1984, 2004, and 2014 in Vicinity of Northern SNORT Alignment.

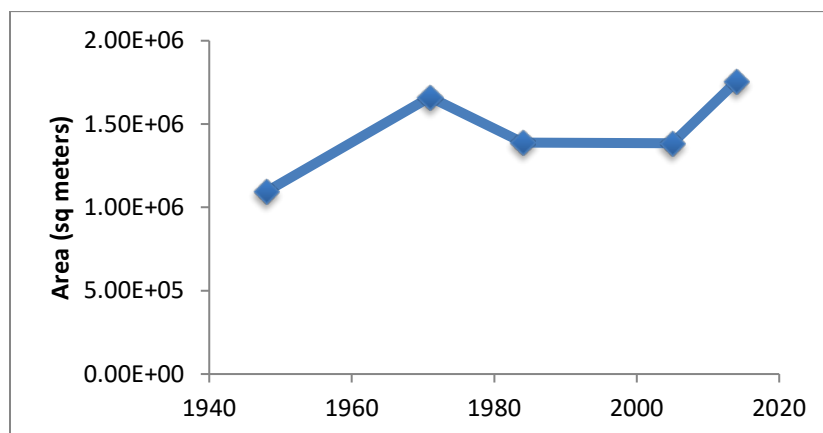


FIGURE 6-2. Plot Showing Areal Extent of Dune Features in Vicinity of Northern SNORT Alignment Over 66-Year Period of Record.

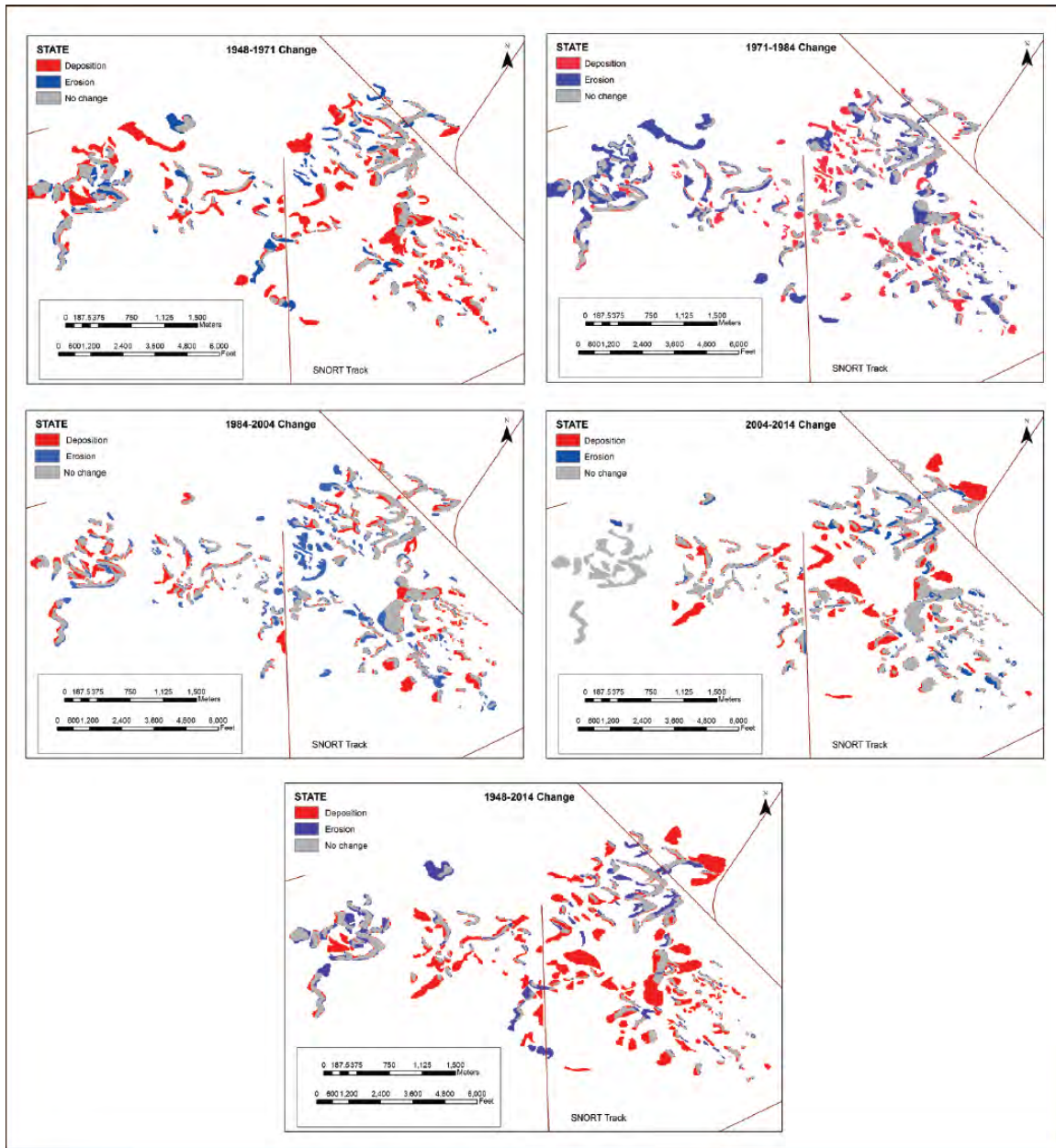


FIGURE 6-3. Maps Showing Spatial Changes in Distribution and Pattern of Erosion, Deposition, and no Change of Dune Features Over Five Time Intervals Between 1948 and 2014.

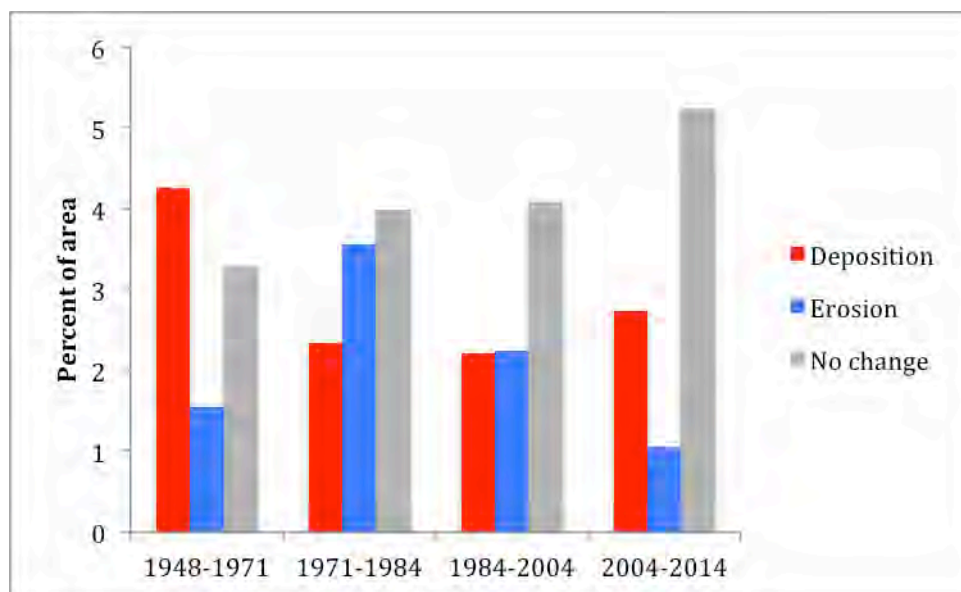


FIGURE 6-4. Histograms Showing Percent Change in Areas of Erosion, Deposition, and no Change of Dune Features Over Four Time Intervals Between 1948 and 2014.

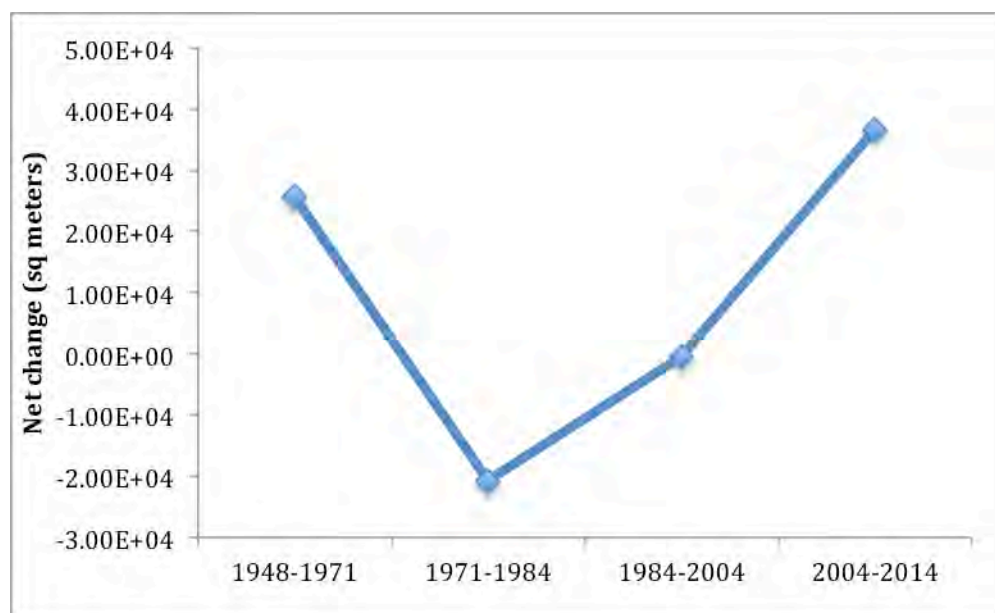


FIGURE 6-5. Plot Showing Net Change in Deposition (Positive) and Erosion (Negative) per Interval of Time in Vicinity of Northern SNORT Alignment.

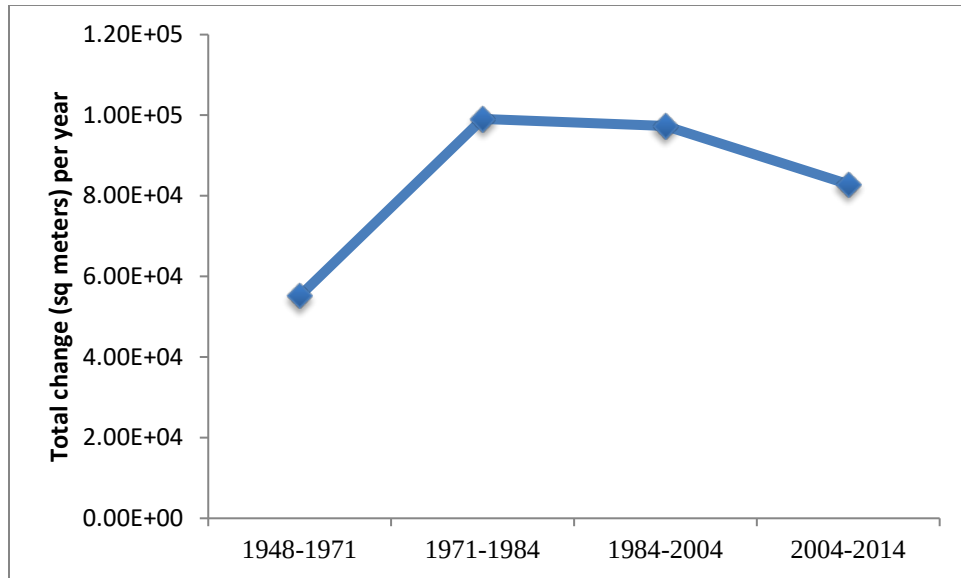


FIGURE 6-6. Plot Showing Total Change of Dune Features (Erosion+Deposition) Indicating Level of Dune Field Activity per Interval of Time in Tvicinity of Northern SNORT Alignment.

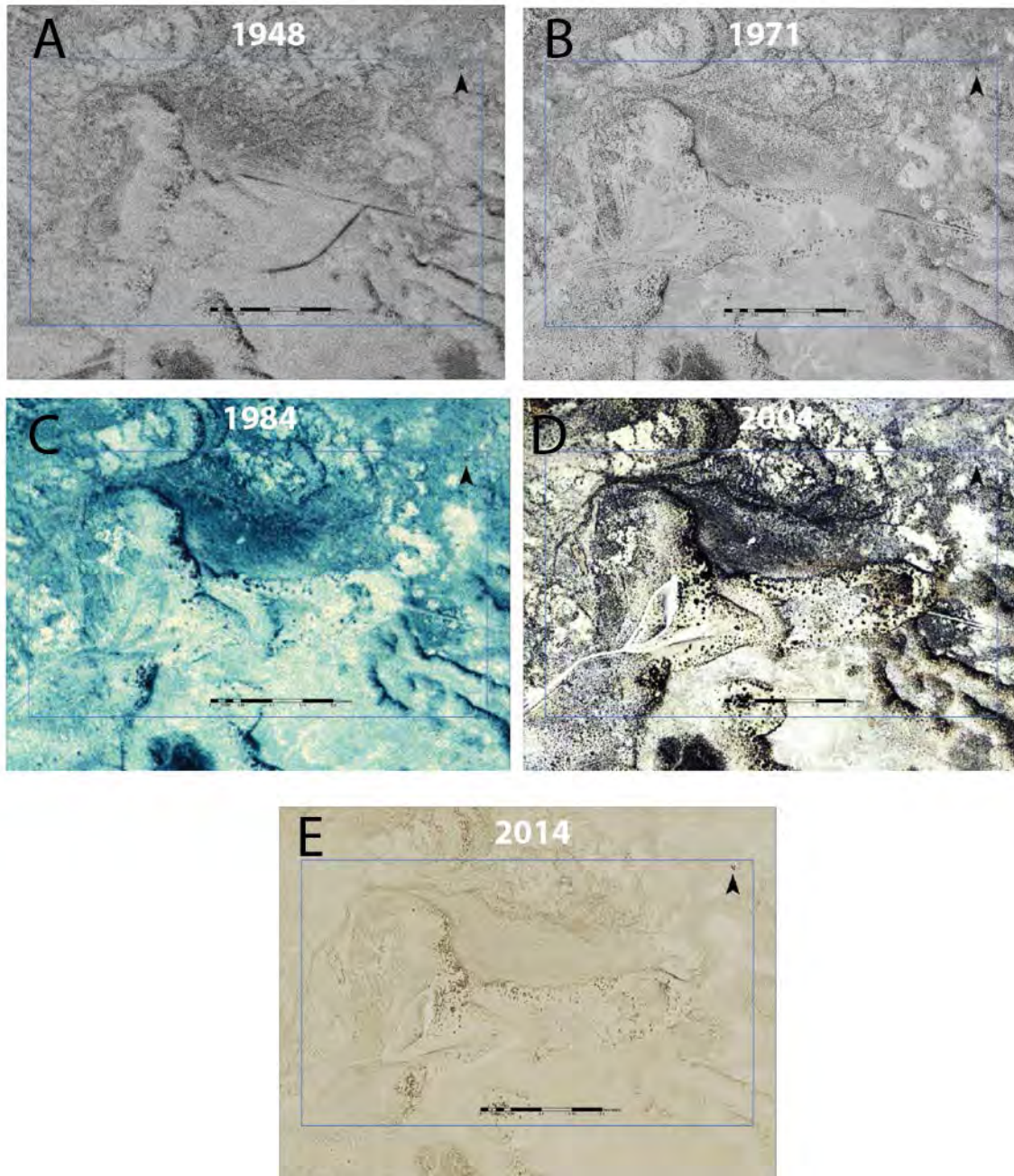


FIGURE 6-7. Images of Area Near KTM 1001 East of SNORT Alignment in: (A) 1948, (B) 1971, (C) 1984, (D) 2004, and (E) 2014.

Note the new dunes formed between 1948 and 1971, and the expansion and migration to the east from 1971 to 1984 that is collectively related to ground disturbance and construction of the KTM pad.

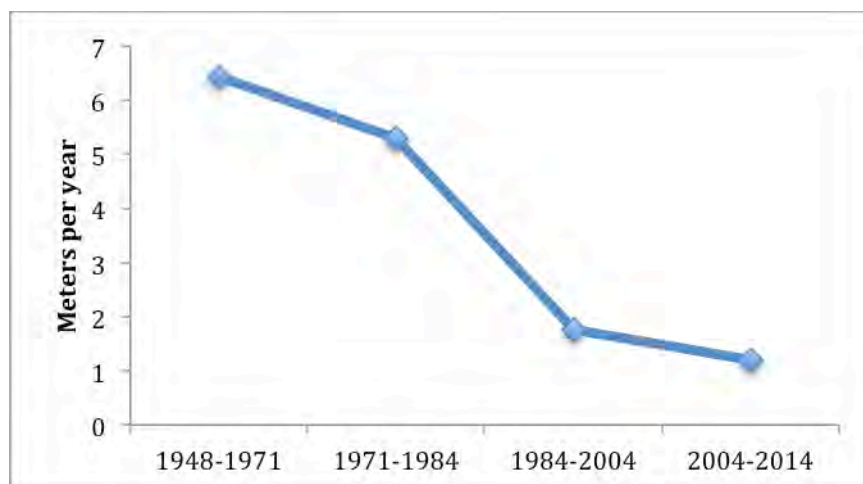


FIGURE 6-8. Plot Showing Decrease in Rate of Dune Expansion to East of Migrating Parabolic Dune at KTM 1001 Site Over Four Time Intervals Between 1948 and 2014.

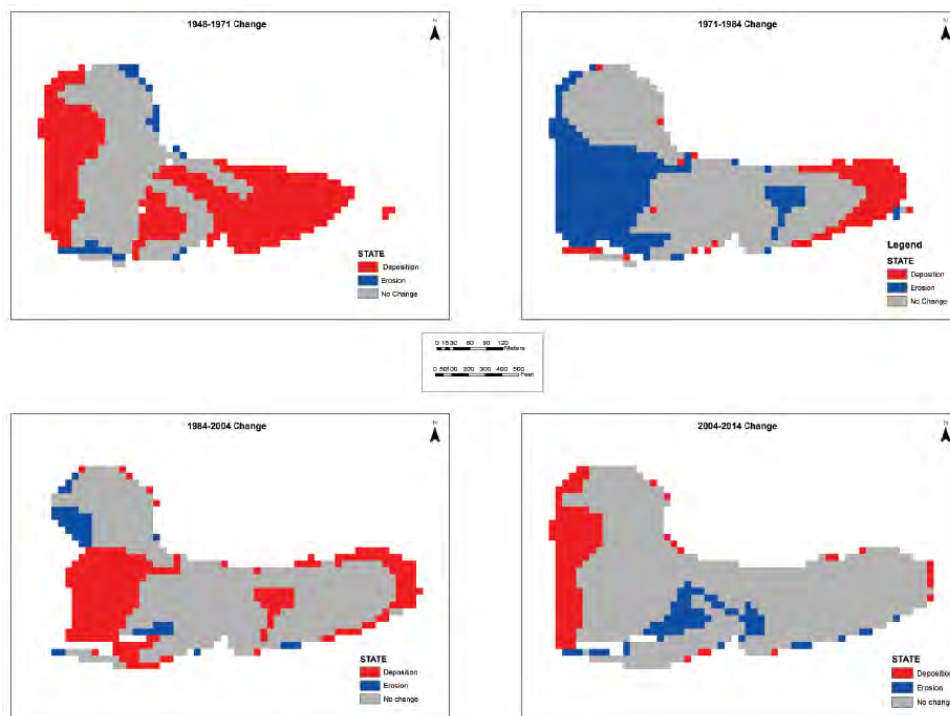


FIGURE 6-9. Maps Showing Time Series of Dune Change of Parabolic Dune Complex at KTM 1001 Site Over Four Time Intervals Between 1948 and 2014. Red: Deposition; Blue: Erosion; Grey: No Change.

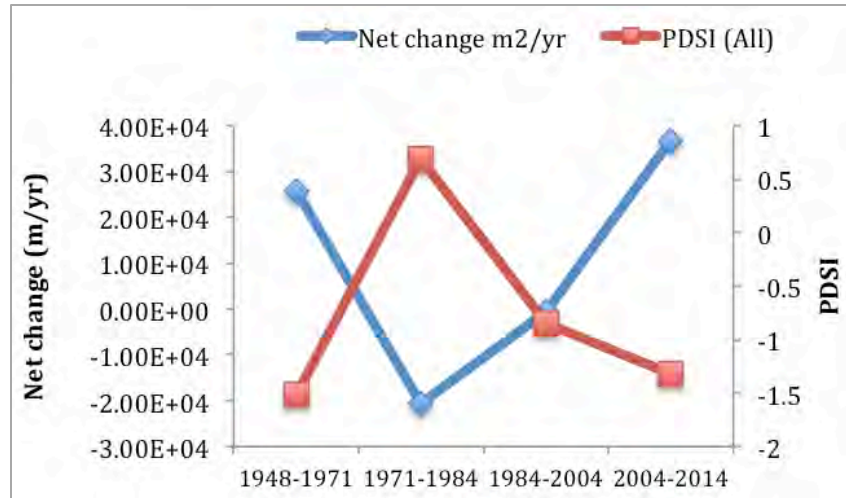


FIGURE 6-10. Plot Showing Net Dune Area Change and Mean PDSI Over Four Time Intervals Between 1948 and 2014.

Positive values represent relatively wetter climatic conditions and negative values represent drier conditions.

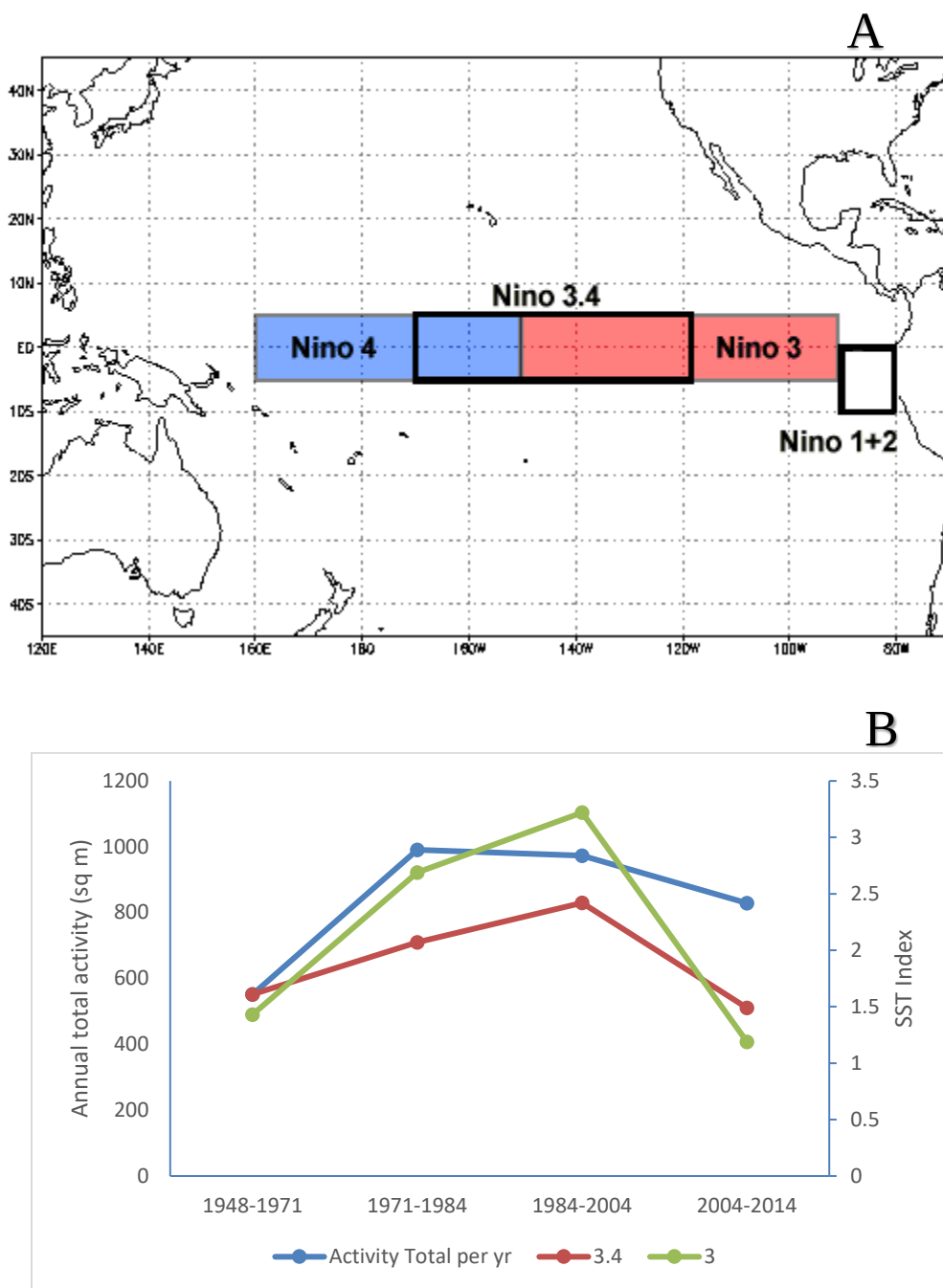


FIGURE 6-11. (A) Map Showing Locations of Sea Surface Temperature Indices of Niño 3 SST and Niño 3.4 SST in Middle and Eastern Pacific Ocean Region, and (B) Plot Showing Total Annual Dune Activity and Maximum Summer/Fall Niño 3 and 3.4 SST Indices.

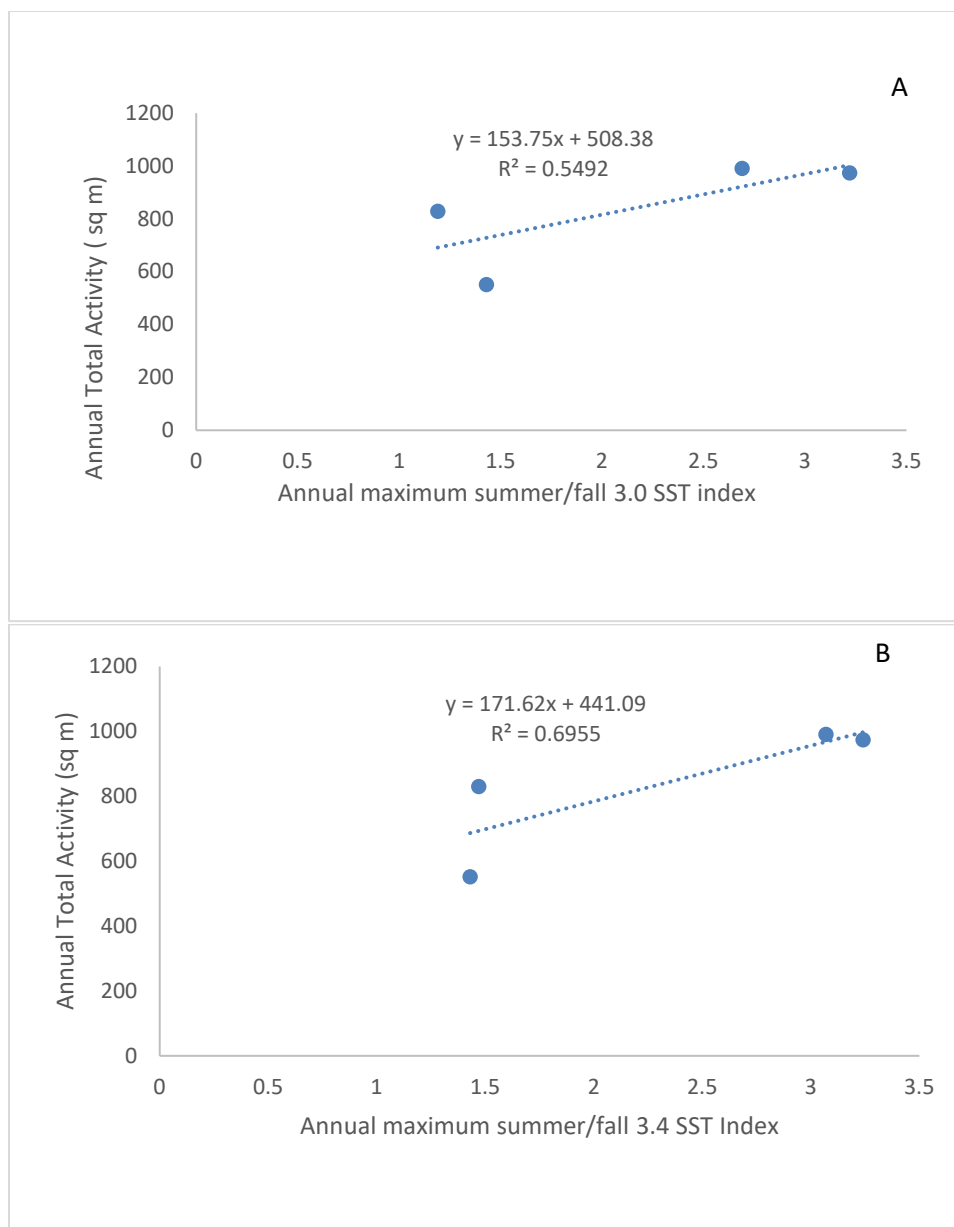


FIGURE 6-12. Plots Showing Correlation Between Total Dune Activity and Maximum Summer/Fall (Niño 3 SST [A] and Niño 3.4 SST [B] Indices for Four Time Intervals Between 1948 and 2014).

Positive values represent relatively stronger ENSO (El Niño-type) conditions and negative values represent relatively weaker (La Niña-type) ENSO conditions.

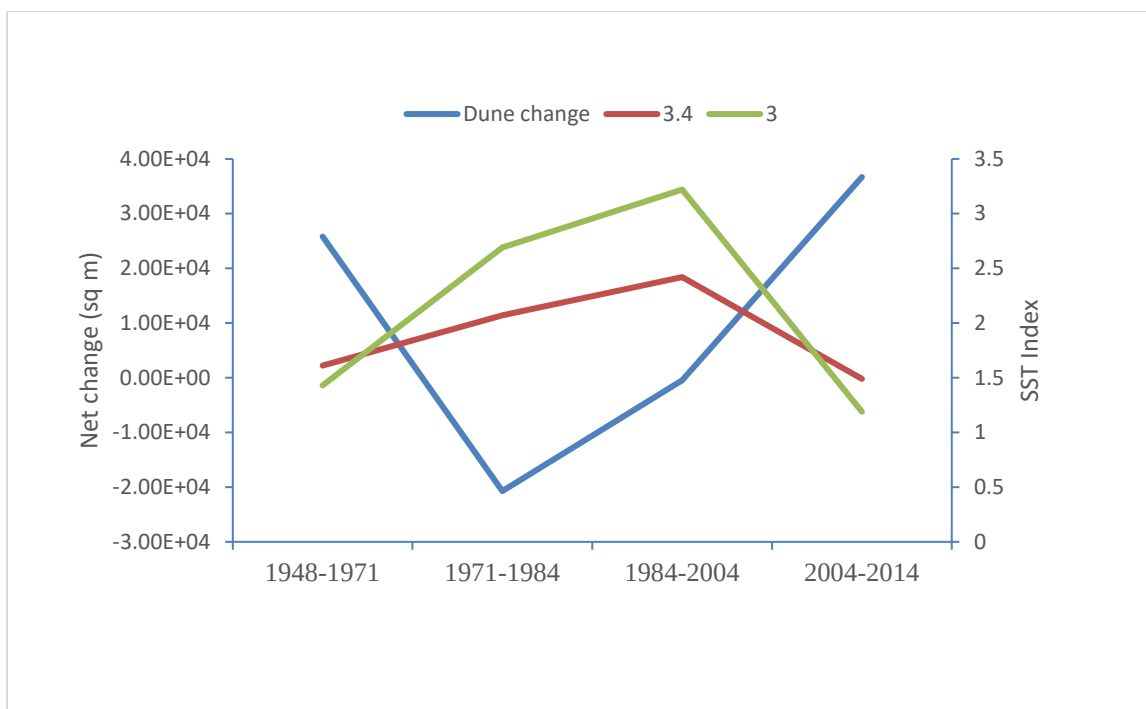


FIGURE 6-13. Plot Showing Relation Between Net Dune Area Change and Maximum Summer/Fall Niño SST Indices for Four Time Intervals Between 1948 and 2014.

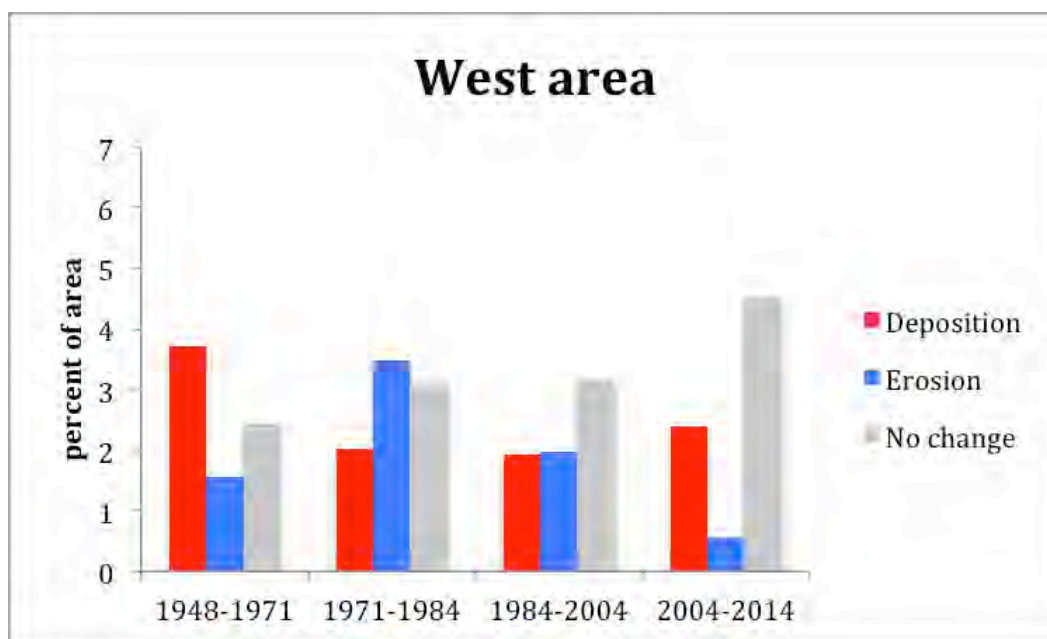


FIGURE 6-14. Histograms Showing Temporal Patterns of Percent Change in Dune Areas West of Little Lake Fault Zone Over Four Time Intervals Between 1948 and 2014.

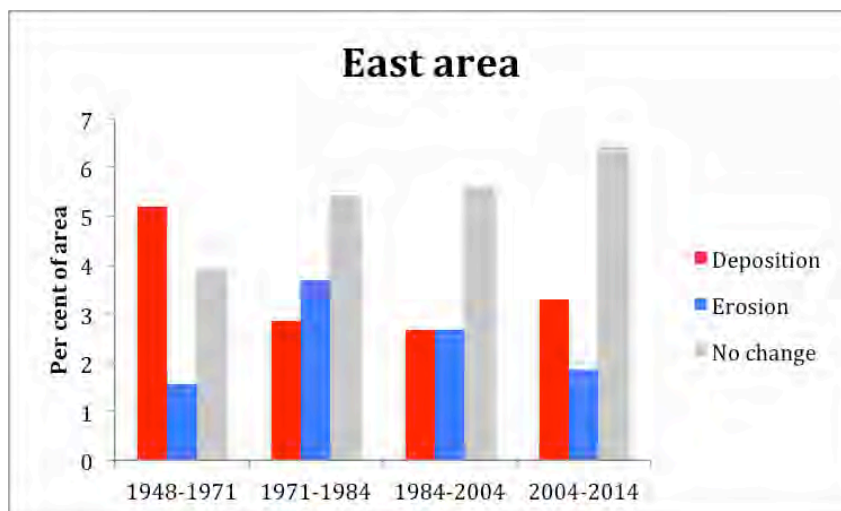


FIGURE 6-15. Histograms Showing Temporal Patterns of Percent Change in Dune Areas East of Little Lake Fault Zone Over Four Time Intervals Between 1948 and 2014.



FIGURE 6-16. Photographs of Dead Vegetation Next to Shovel (Top) and a Dune Blowout Feature Caused by Vegetation Loss (Bottom) Located Southeast of KTM 1001 Site. (Photographs taken in February 2016.)

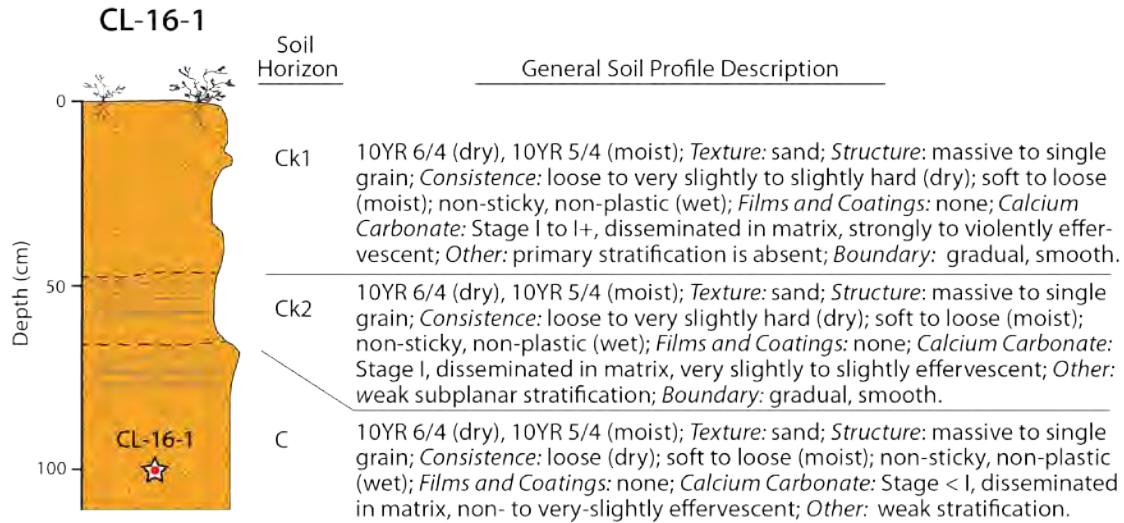
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Appendix A
DATA SUPPORTING SECTION 4.0

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SOIL-STRATIGRPHIC DESCRIPTIONS

For location of profiles, see Figures 4.2 and 4.3.



EXPLANATION

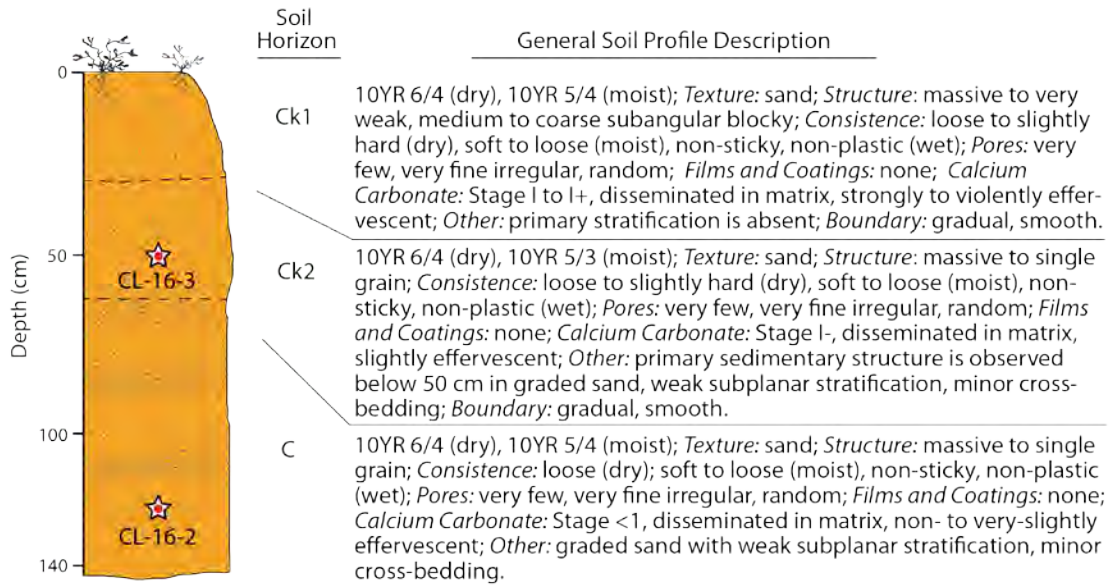


Aeolian Sand - very pale brown (10YR 6/4), massive, silty, fine- to medium-grained, sub-angular to subrounded quartz-rich aeolian sand, lightly frosted grains (primarily rounded and well-rounded grains); few to common silt-size opaque grains and fine to very-fine, subangular lithic grains. No clay observed in sand deposits; silt coatings on some sand grains (also bridging grains, lining pores) imparts weak soil structure. Weak subplanar stratification and cross bedding in Ck2 and C horizons, but absent in Ck1 horizon.



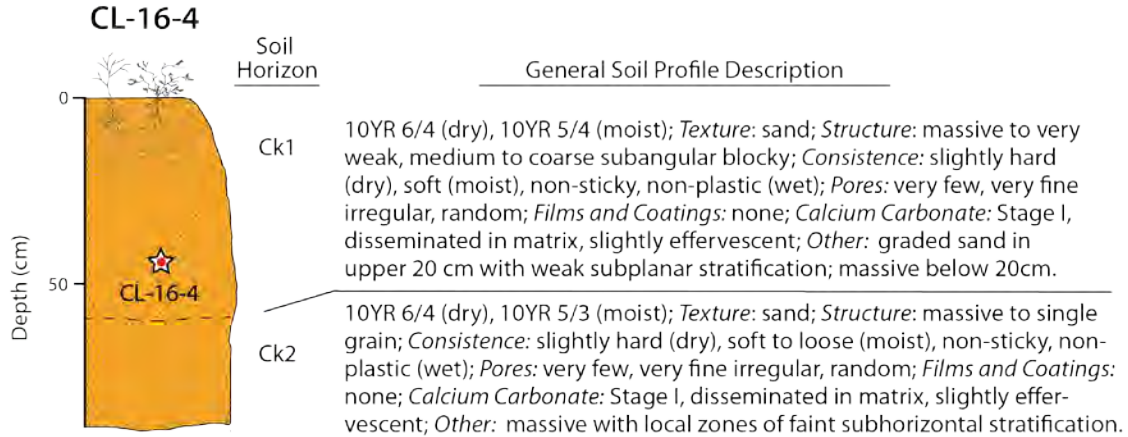
Luminescence sample location and sample number

CL-16-2, CL-16-3



EXPLANATION

-  **Aeolian Sand** - very pale brown (10YR 6/4), massive, silty, fine- to medium-grained, sub-angular to subrounded quartz-rich aeolian sand, lightly frosted grains (primarily; rounded and well-rounded grains), few to common silt-size opaque grains and fine to very-fine, subangular lithic grains. No clay observed in sand deposit; silt coatings on sand grains (also bridging grains, lining pores) imparts weak soil structure. Weak subplanar stratification and cross bedding in Ck2 and C horizons, but absent in Ck1 horizon.
-  Luminescence sample location and sample number



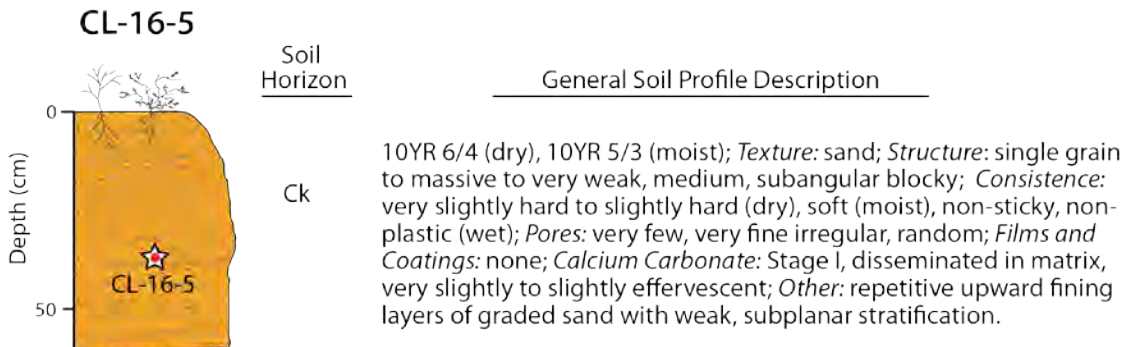
EXPLANATION



Aeolian Sand - very pale brown (10YR 6/4), massive, silty, fine- to medium-grained, sub-angular to subrounded quartz-rich aeolian sand, lightly frosted grains (primarily rounded and well-rounded grains); few to common silt-size opaque grains and fine to very-fine, subangular lithic grains. No clay observed in sand deposits; silt coatings on some sand grains (also bridging grains, lining pores) imparts weak soil structure. Weak subplanar stratification and cross bedding observed in upper 20-30 cm.



Luminescence sample location and sample number



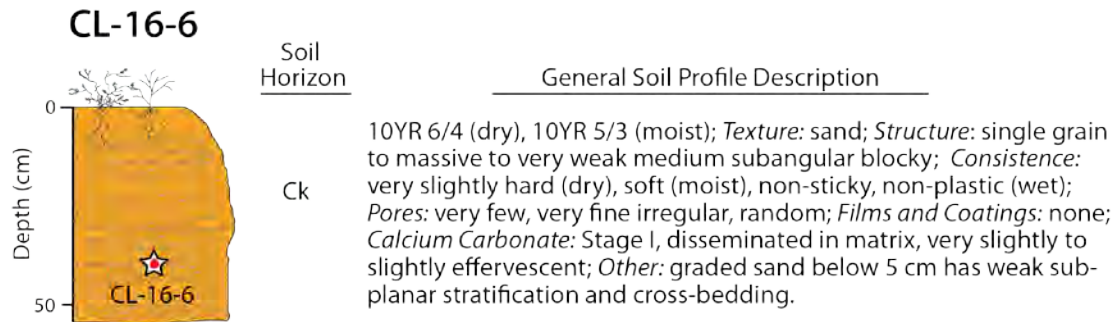
EXPLANATION



Aeolian Sand - very pale brown (10YR 6/4), massive, silty, fine- to medium-grained, sub-angular to subrounded quartz-rich aeolian sand, lightly frosted grains (primarily rounded and well-rounded grains); few to common silt-size opaque grains and fine to very-fine, subangular lithic grains. No clay observed in sand deposits; silt coatings on some sand grains (also bridging grains, lining pores) imparts weak soil structure. Weak, subplanar stratification and cross bedding.



Luminescence sample location and sample number



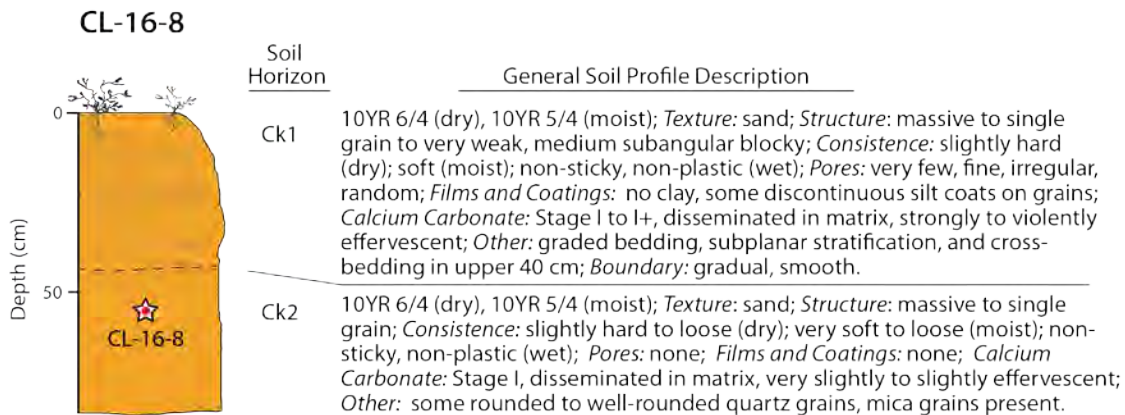
EXPLANATION



Aeolian Sand - very pale brown (10YR 6/4), massive, silty, fine- to medium-grained, subangular to subrounded quartz-rich aeolian sand, lightly frosted grains (primarily rounded and well-rounded grains); few to common silt-size opaque grains and fine to very-fine, subangular lithic grains. No clay observed in sand deposit; silt coatings on sand grains (also bridging grains, lining pores) imparts weak soil structure. Weak sub-planar stratification and cross bedding.



Luminescence sample location and sample number



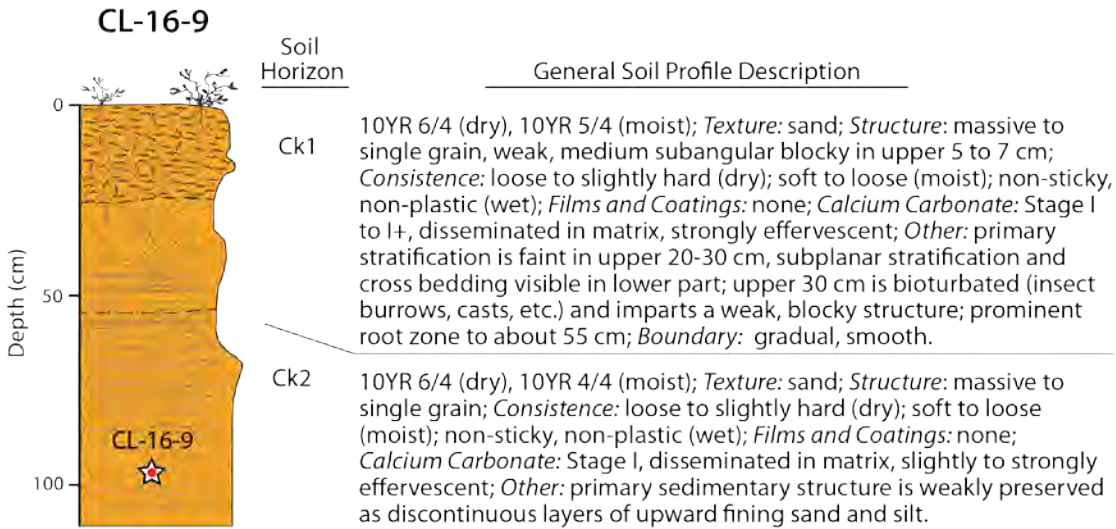
EXPLANATION



Aeolian Sand and Silt - very pale brown (10YR 6/4), massive, silty, fine- to medium-grained, subangular to subrounded (some rounded to well-rounded) quartz- and mica- rich aeolian sand, lightly frosted grains (primarily rounded and well-rounded grains); few to common silt-size opaque grains and fine to very-fine, subangular lithic grains. No clay observed in sand deposits; silt coatings on some sand grains (also bridging grains, lining pores) imparts weak soil structure. Subplanar stratification and cross bedding in upper 40 cm.



Luminescence sample location and sample number



EXPLANATION



Aeolian Sand - very pale brown (10YR 6/4), massive, silty, fine- to medium-grained, sub-angular to subrounded quartz-rich aeolian sand, lightly frosted grains (primarily rounded and well-rounded grains); few to common silt-size opaque grains and fine to very-fine, subangular lithic grains. No clay observed in sand deposits; silt coatings on some sand grains (also bridging grains, lining pores) imparts weak soil structure. Subplanar stratification and cross bedding present in lower Ck1 horizon and in Ck2 horizon.



Luminescence sample location and sample number

Appendix B
DATA SUPPORTING SECTION 5.0

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XRD BULK MINERALOGY

China Lake—Bulk XRD Analysis

Prepared by: Sophie Baker

April-May 2016

SAMPLE PREPARATION METHODS:

The 20 sediment samples from China Lake were prepared for bulk XRD analysis by splitting out ~6g of the oven dried <2mm fraction of the sample and grinding it by hand in a pestle and mortar until it passed through a sieve with openings of 500 μ m. Samples were then ground to a powder in a McCrone mill for 8 minutes in 10 ml of methanol. Subsequently, samples were air dried overnight, gently re-crushed in a pestle and mortar to break up aggregates formed during drying, and side-loaded into specially-designed side-loading sample holders. This process of grinding the samples to a fine homogenous powder, followed by side-loading, helps to reduce preferred orientation of certain crystal phases within the samples, which is important for semi-quantitative analysis; however a certain amount of preferred orientation still tends to occur.

ANALYSIS PARAMETERS:

All samples were run on DRI's Bruker D8 Advance XRD equipped with a Vantec PSD detector. The following scan parameters were used:

- 5 to 60° 2-Theta scan range
- Locked Coupled Continuous Scan
- 0.021° 2-Theta increments (step size)
- 1 second/step (scan speed)
- Variable width divergence and anti-scatter slits (V12)
- Sample rotation speed of 15 rpm
- 31-34 kV/40 mA X-Ray power

DATA ANALYSIS METHODS:

The resulting XRD scans were viewed and interpreted using the Bruker XRD data evaluation software called EVA. A background correction, a K-alpha2 stripping operation (0.5 ratio), and x-offset correction were performed on each scan before interpretation. Minerals were identified by matching reference mineral patterns stored in the ICDD database to the observed peaks.

The method used to estimate the relative percentages of each mineral identified (i.e., the semi-quantitative analysis) is based on the method of Chung (1975), which assumes that all the minerals are identified correctly and that there are no unidentified phases in the sample. It is carried out within EVA by adjusting the y-scale of the reference patterns (visually represented by sticks in the plots) to match the peak

heights on the observed scan. A reference intensity ratio for each mineral (in this case, I/I_c , which is the relative height of the strongest peak of a mineral compared to the relative height of the strongest peak of corundum in a 1:1 mixture) is then used to determine the relative percentages. The calculation is done automatically by the software once each mineral selected is assigned an I/I_c value. The I/I_c values for most of the mineral reference patterns used were provided by the ICDD database. Otherwise values were taken from Davis *et al.* (1989). Because generic I/I_c values were used (the same basic mineral type can have a range of I/I_c values), the relative percentages of the mineral determined can be assumed only to be semi-quantitative estimations rather than quantitative values (no estimation of uncertainty can be provided). Preferred orientation of mineral crystals, a certain amount of which is unavoidable during sample mounting, may also cause inaccuracies in the calculated percentages.

RESULTS:

Table B1 shows the results of the semi-quantitative analysis, and Appendix 5A-1 shows the scans for each sample including the reference patterns (stick patterns) for identified minerals.

The scans for all samples are very similar and indicate that quartz and plagioclase are the two major minerals (present at concentrations $>\sim 20\%$). Results suggest that together quartz and plagioclase comprise ~ 75 -90 percent of the identified mineral content. K-feldspar appears to be the third most concentrated mineral in all samples, occurring in minor amounts (~ 5 -20% of the identified mineral content). The scans suggest that calcite is present in minor amounts (~ 5 -20%) in 12 of the 20 samples and in trace ($<\sim 5\%$) amounts in 5 samples, while it is below detection limit in 3 samples. Results also suggest that amphibole is present in trace amounts in 12 or 15 samples. The lack of amphibole peaks in the other scans may be a result of the fact that XRD methods cannot reliably detect components present at <5 percent.

Many sample scans showed small narrow peaks that cannot reliably be attributed to a particular mineral. In an attempt to determine if the peaks truly represented mineral patterns or if they were an artifact of irregular voltages in the new X-ray tube (installed in March 2016), all samples were reanalyzed at a lower voltage (31 kV as opposed to 34 kV) voltages, and several samples were analyzed three or four times. In nearly all cases, these peaks were not consistent across scans, and fewer occurred in the lower voltage scan, indicating that they do not reflect the presence of important minerals. The lowest voltage (31kV) scans were used in the final semi-quantitative analysis. An attempt was made to match reference mineral patterns with any peaks that occurred in these 31 kV scans. Any reasonable but uncertain matches are listed in Table B1 under the 'Other' category. In Appendix 5A-1, the 31 kV scan for each sample is shown with the mineral reference stick patterns, followed by a plot showing all scans run for that sample with no reference patterns.

REFERENCES

- Chung, F. H., 1975. Quantitative interpretation of X-ray diffraction patterns of mixtures. III. Simultaneous determination of a set of reference intensities. *Journal of Applied Crystallography* 8 (17-19).
- Davis, B. L., Smith, D.K., Holomany, M.A., 1989. Tables of Experimental Reference Intensity Ratios Table No. 2, December 1989. *Powder Diffraction* 4:4 (201-205).

TABLE B-1. Results of Semi-Quantitative Bulk XRD Analysis for China Lake Samples.
 Percentages shown are rough estimates only. Categories of major, minor,
 and trace should be quoted rather than percentages.

		Major	>20%	Minor	5-20%	Trace	<5%	
		Semi-quantitative XRD results (percentages are approximate only)						
Field ID	Lab ID	Quartz	Plagioclase	K-feldspar	Calcite	Amphibole	Other	Total
CL-16-1	16-321	37	44	11	8	-		100
		Major	Major	Minor	Minor			
CL-16-2	16-322	40	39	12	9	-	Trace clays or loughlinite or sepiolite possible	100
		Major	Major	Minor	Minor			
CL-16-3	16-323	35	43	13	9	Trace possible		100
		Major	Major	Minor	Minor			
CL-16-4	16-324	32	47	11	10	Trace	Trace paracoquimbite or laurite possible	100
		Major	Major	Minor	Minor	Trace		
CL-16-5	16-325	43	36	12	9	Trace		100
		Major	Major	Minor	Minor	Trace		
CL-16-6	16-326	40	40	12	8	Trace	Trace chamosite possible	100
		Major	Major	Minor	Minor	Trace		
CL-16-7	16-327	28	47	10	15	Trace		100
		Major	Major	Minor	Minor	Trace		
CL-16-8	16-328	43	38	12	7	Trace		100
		Major	Major	Minor	Minor	Trace		
CL-16-9	16-329	42	40	11	7	Trace possible	Trace clays or sepiolite possible	100
		Major	Major	Minor	Minor			
CL-16-11	16-330	43	44	13	Trace	Trace possible	Trace clays possible	100
		Major	Major	Minor	Trace			
CL-16-12	16-331	37	47	16	Trace	-		100
		Major	Major	Minor	Trace			

TABLE B-1 (Cont'd). Results of Semi-Quantitative Bulk XRD Analysis for China Lake Samples.
 Percentages shown are rough estimates only. Categories of major, minor, and trace
 should be quoted rather than percentages (continued).

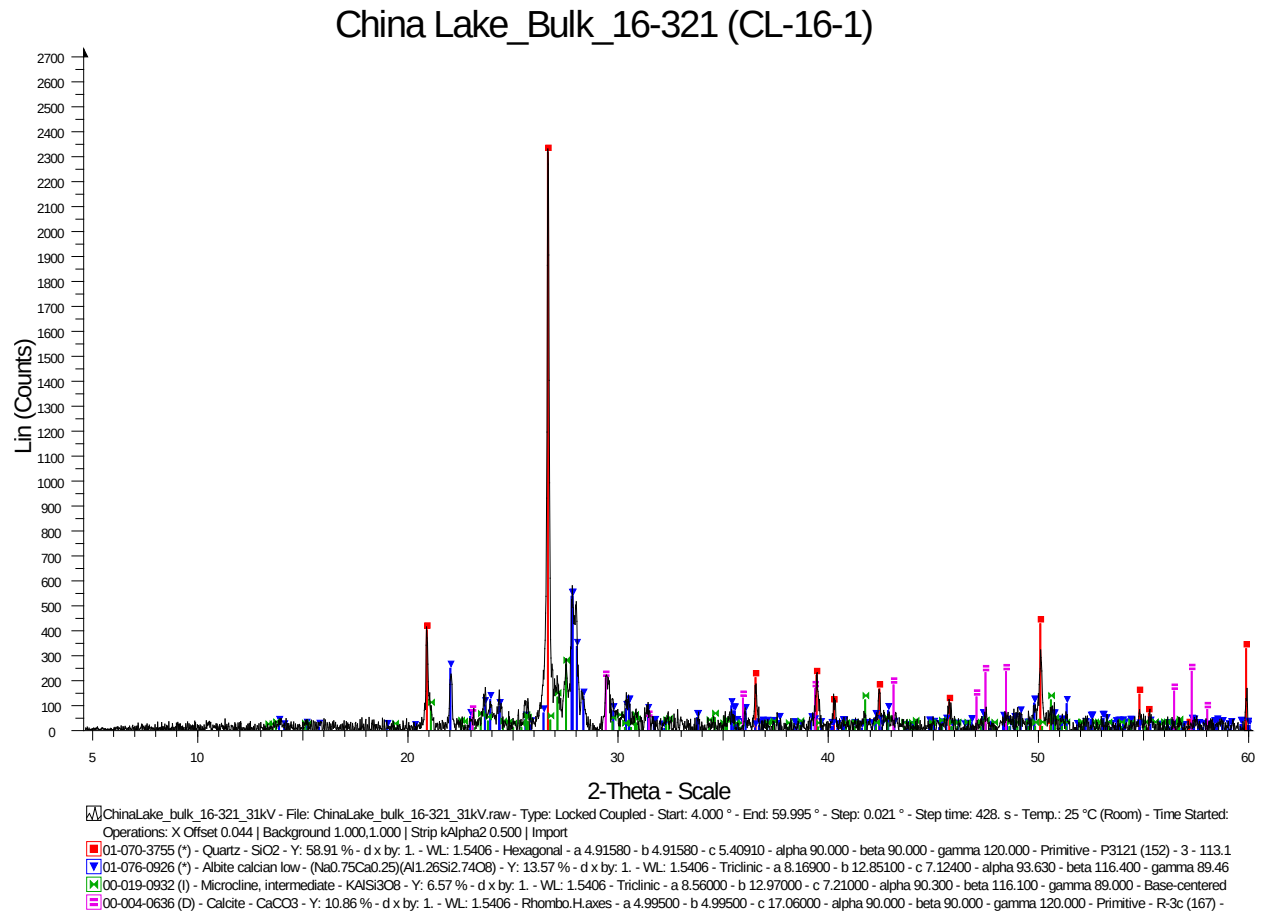
		Major	>20%	Minor	5-20%	Trace	<5%	
		Semi-quantitative XRD results (percentages are approximate only)						
Field ID	Lab ID	Quartz	Plagioclase	K-feldspar	Calcite	Amphibole	Other	Total
CL-16-13	16-332	36	47	17	Trace	Trace		100
		Major	Major	Minor	Trace	Trace		
CL-16-14	16-333	40	45	15	Trace	Trace		100
		Major	Major	Minor	Trace	Trace		
CL-16-15	16-334	39	46	15	Trace	Trace	Trace hematite possible	100
		Major	Major	Minor	Trace	Trace		
CL-16-16	16-335	44	40	11	5	-		100
		Major	Major	Minor	Minor			
CL-16-17	16-336	39	44	9	8	Trace		100
		Major	Major	Minor	Minor	Trace		
CL-16-18	16-337	38	50	12	-	Trace		100
		Major	Major	Minor		Trace		
CL-16-19	16-338	43	44	13	-	Trace	Trace clays possible	100
		Major	Major	Minor		Trace		
CL-16-20	16-339	38	42	12	8	Trace	Trace other mineral such as sauconite, pyrophyllite possible	100
		Major	Major	Minor	Minor	Trace		
CL-16-21	16-340	49	32	19	-	-	Trace clays or micas and/or paracoquimbite possible	100
		Major	Major	Minor				

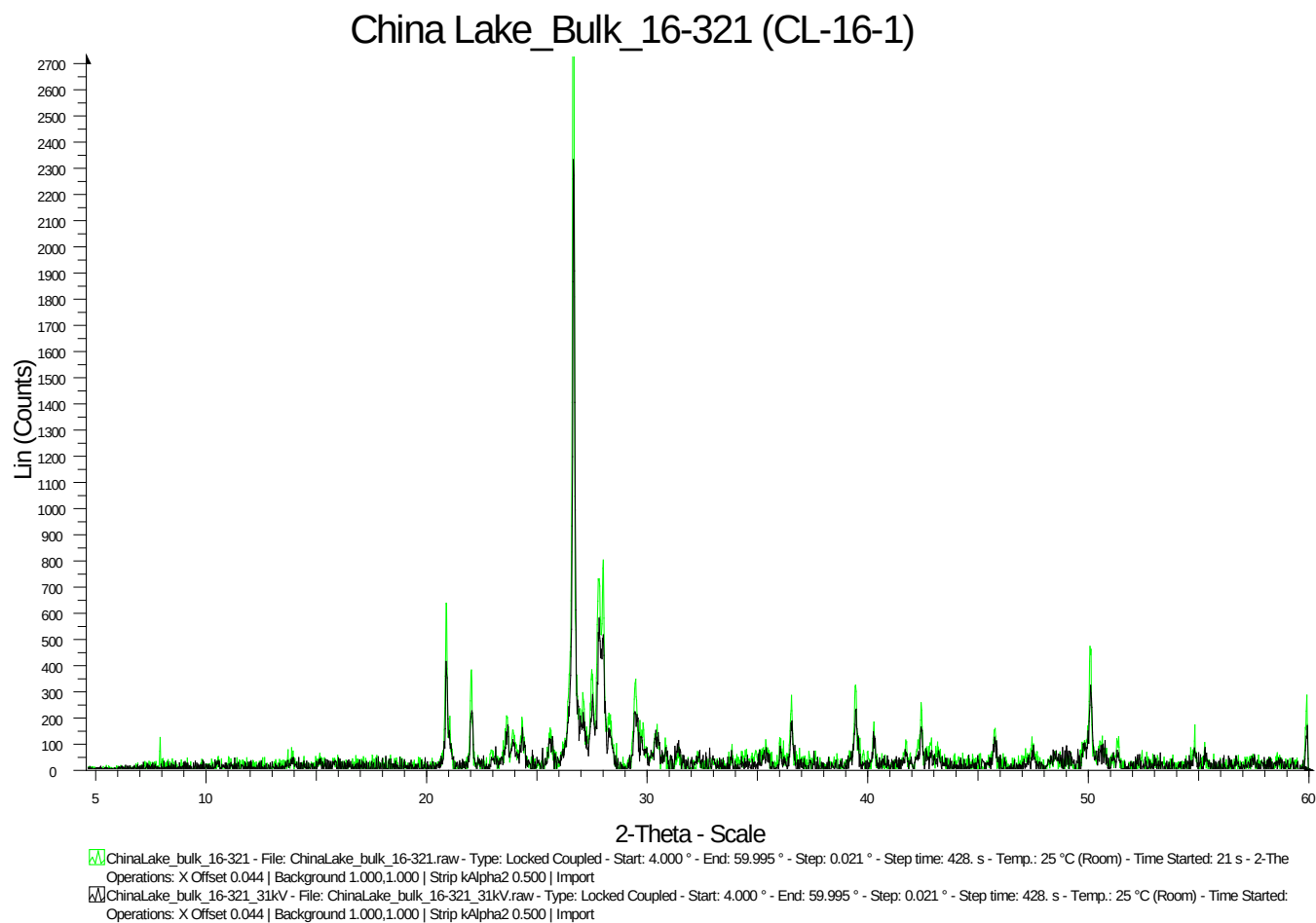
Appendix C

XRD SCANS FOR CHINA LAKE SAMPLES

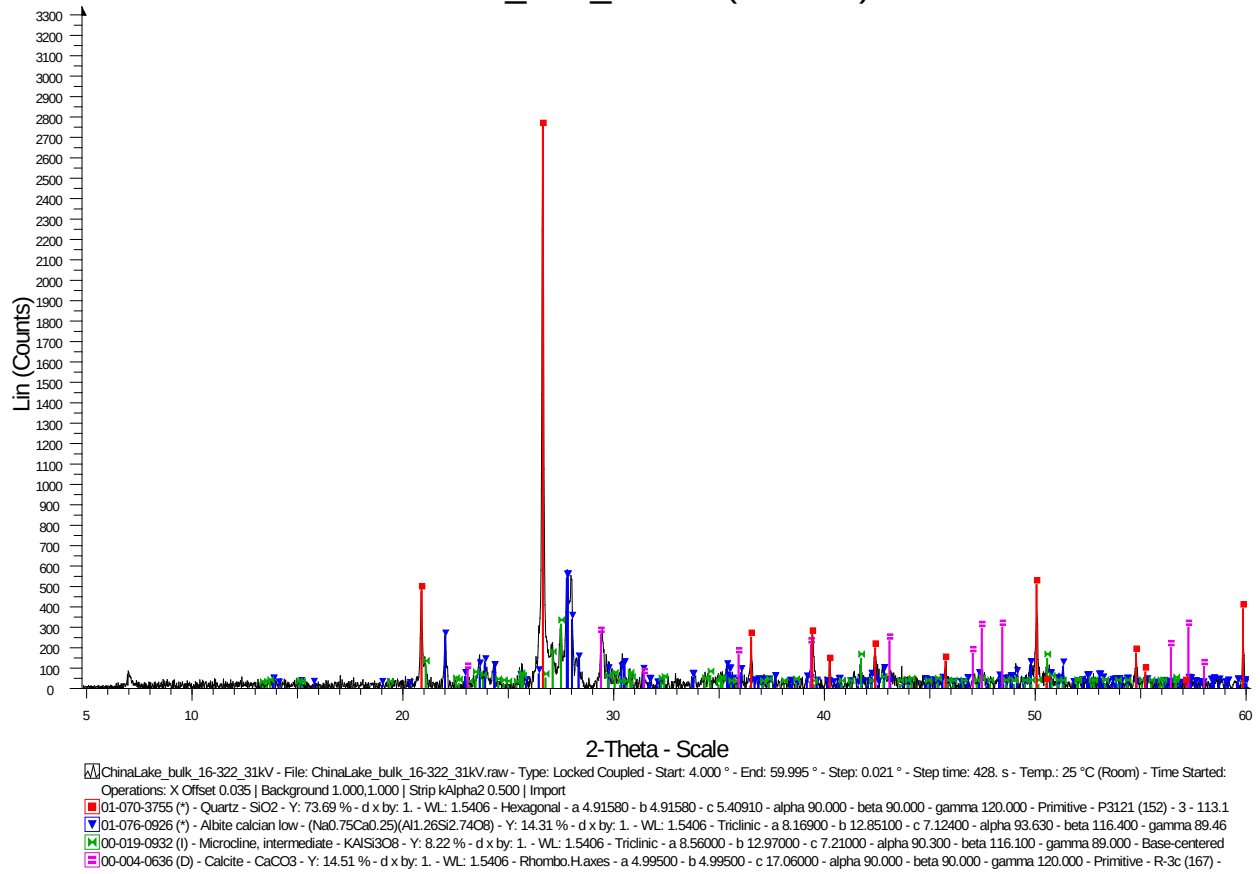
NOTE: There are at least two plots for each sample. The first shows the lowest voltage scan (31kV) and the reference patterns for the minerals identified on that scan. In some cases, there is more than one plot with mineral reference patterns shown for a particular sample – this is because in these subsequent plots there are one or two additional possible minerals shown. The identification of these minerals is much more speculative than the minerals shown in the first plot. Lastly for each sample, there is a plot showing all scans obtained for the sample, with no reference patterns visible.

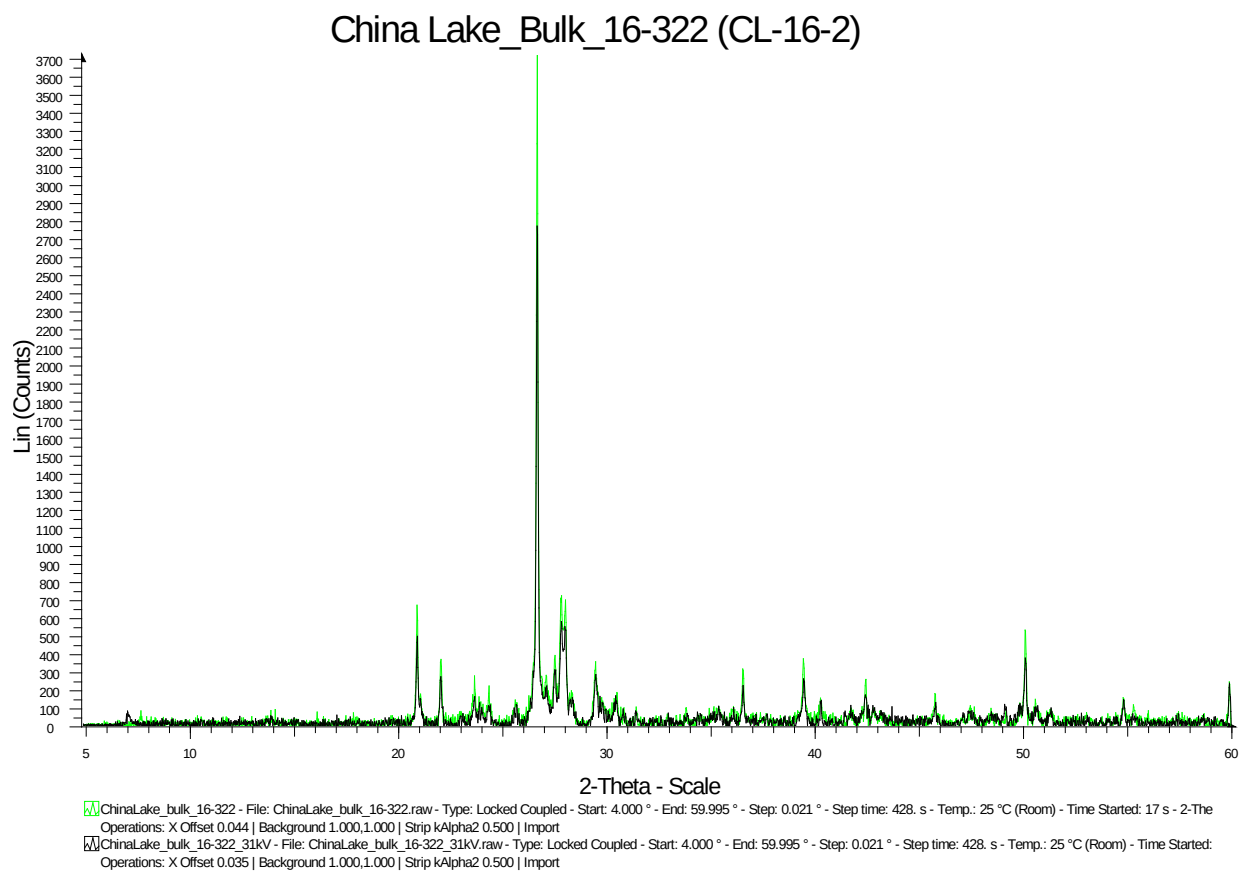
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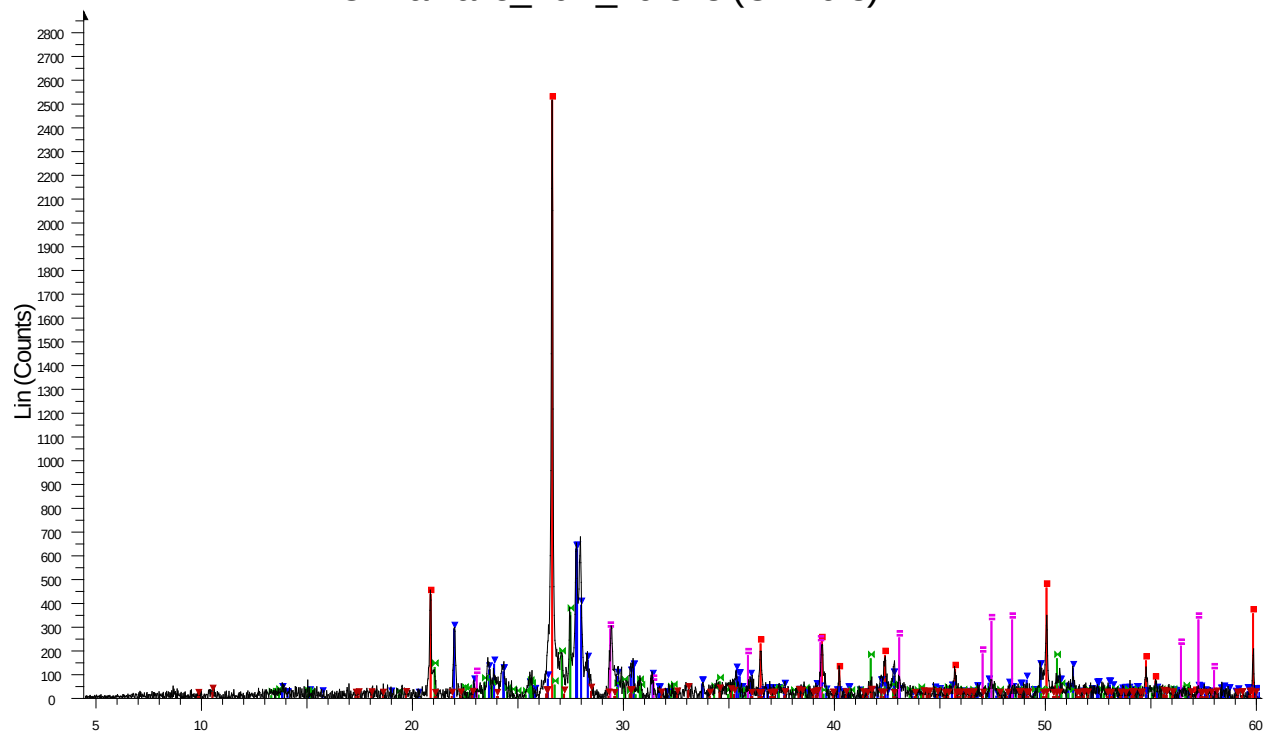


China Lake_Bulk_16-322 (CL-16-2)





China Lake_Bulk_16-323 (CL-16-3)



ChinaLake_bulk_16-323_31kV - File: ChinaLake_bulk_16-323_31kV.raw - Type: Locked Coupled - Start: 4.000 ° - End: 59.995 ° - Step: 0.021 ° - Step time: 428. s - Temp.: 25 °C (Room) - Time Started:
 Operations: X Offset 0.044 | Background 1.000,1.000 | Strip kAlpha2 0.500 | Import

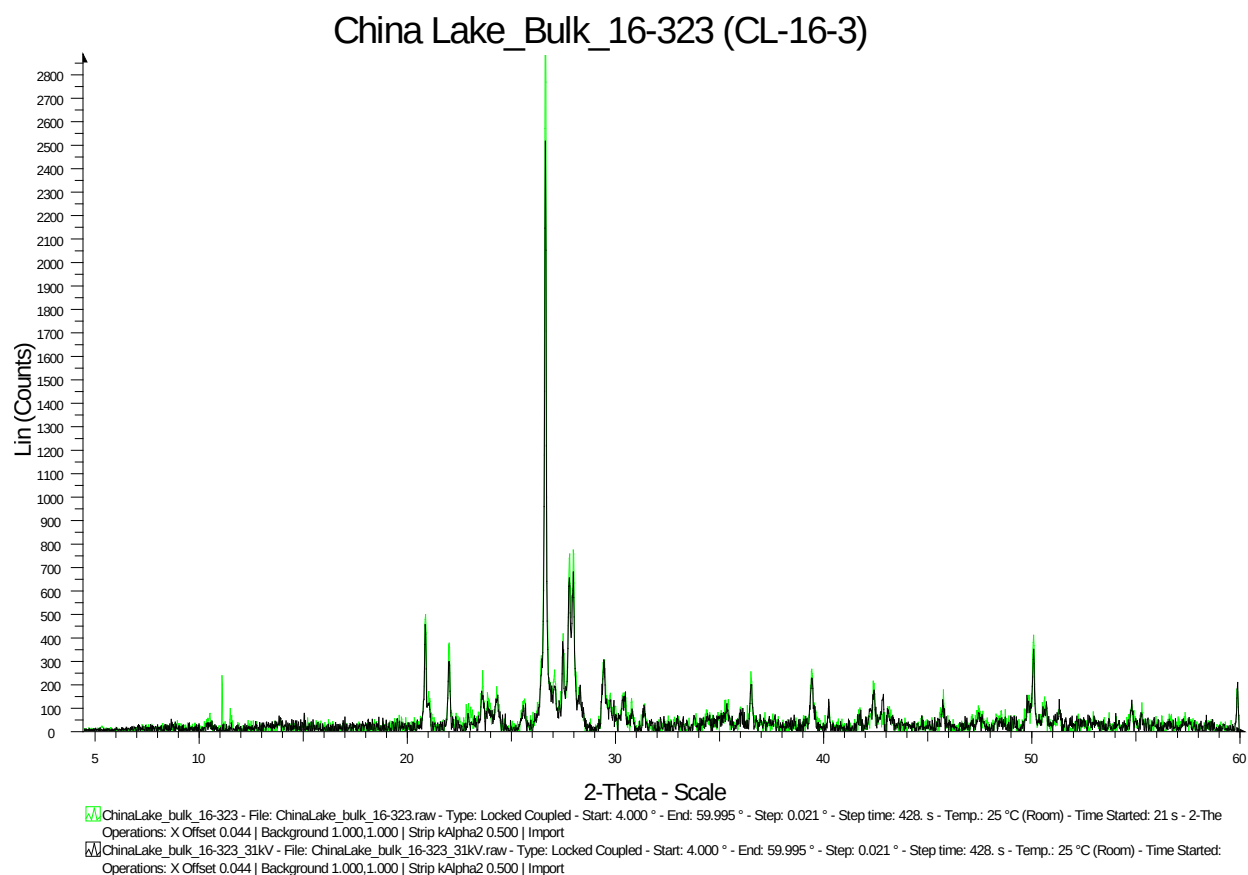
01-070-3755 (*) - Quartz - SiO₂ - Y: 73.24 % - d x by: 1. - WL: 1.5406 - Hexagonal - a 4.91580 - b 4.91580 - c 5.40910 - alpha 90.000 - beta 90.000 - gamma 120.000 - Primitive - P3121 (152) - 3 - 113.1

01-076-0926 (*) - Albite calcian low - (Na_{0.75}Ca_{0.25})(Al_{1.26}Si_{2.74}O₈) - Y: 18.15 % - d x by: 1. - WL: 1.5406 - Triclinic - a 8.16900 - b 12.85100 - c 7.12400 - alpha 93.630 - beta 116.400 - gamma 89.46

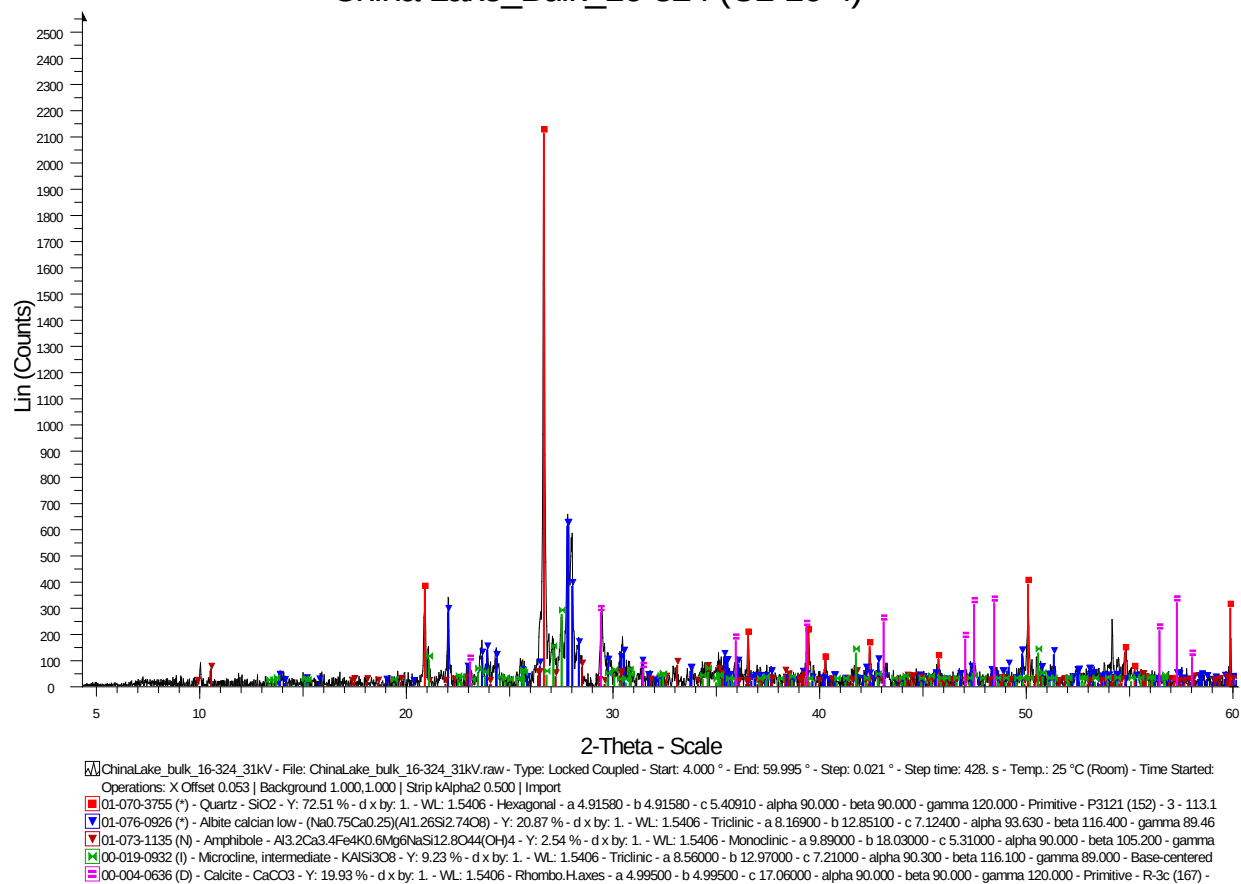
01-073-1135 (N) - Amphibole - Al_{3.2}Ca_{3.4}Fe₄K_{0.6}Mg₆NaSi_{12.8}O₄₄(OH)₄ - Y: 0.71 % - d x by: 1. - WL: 1.5406 - Monoclinic - a 9.89000 - b 18.03000 - c 5.31000 - alpha 90.000 - beta 105.200 - gamma

00-019-0932 (I) - Microcline, intermediate - KAlSi₃O₈ - Y: 10.35 % - d x by: 1. - WL: 1.5406 - Triclinic - a 8.56000 - b 12.97000 - c 7.21000 - alpha 90.300 - beta 116.100 - gamma 89.000 - Base-center

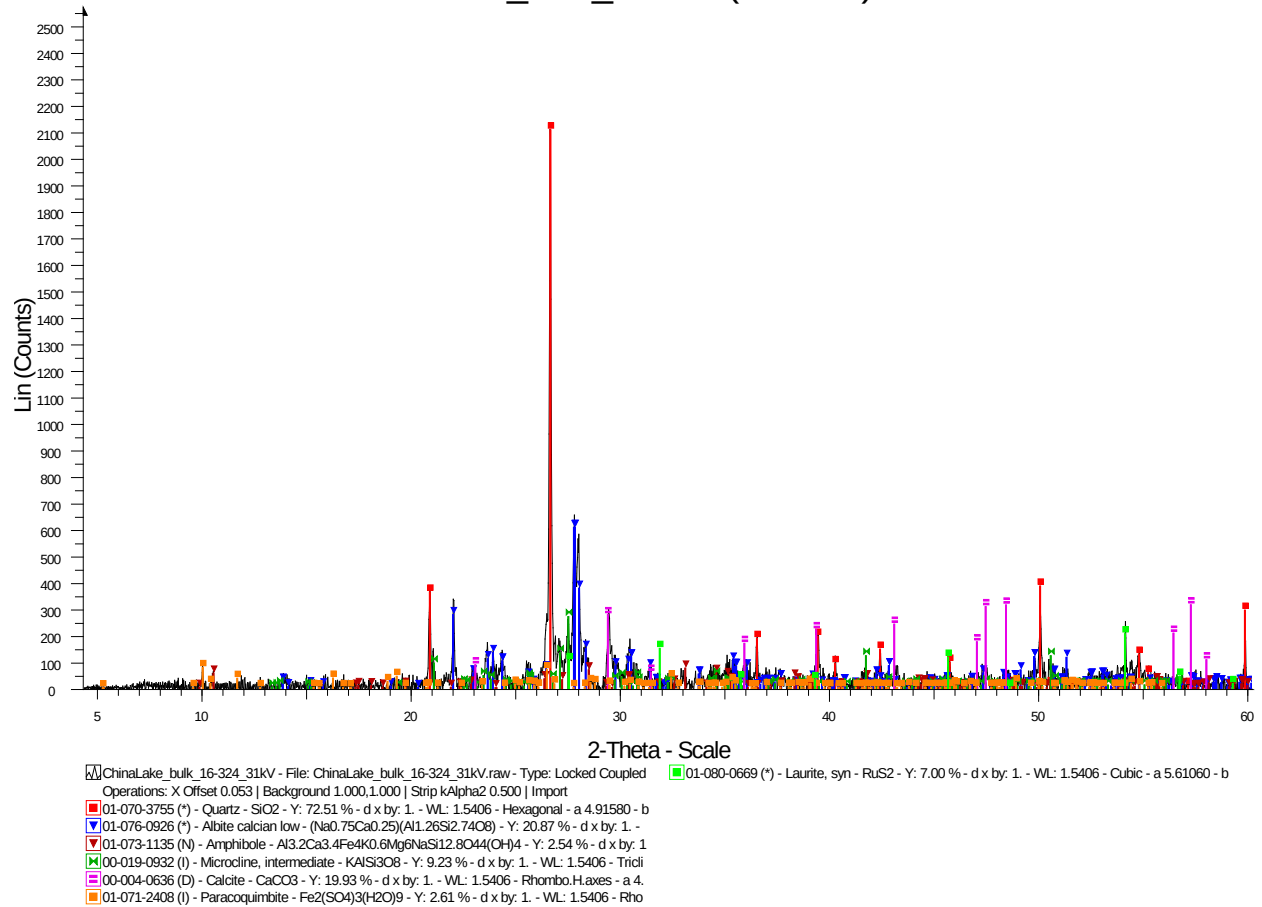
00-004-0636 (D) - Calcite - CaCO₃ - Y: 17.44 % - d x by: 1. - WL: 1.5406 - Rhombo.Haxes - a 4.99500 - b 4.99500 - c 17.06000 - alpha 90.000 - beta 90.000 - gamma 120.000 - Primitive - R-3c (167) -

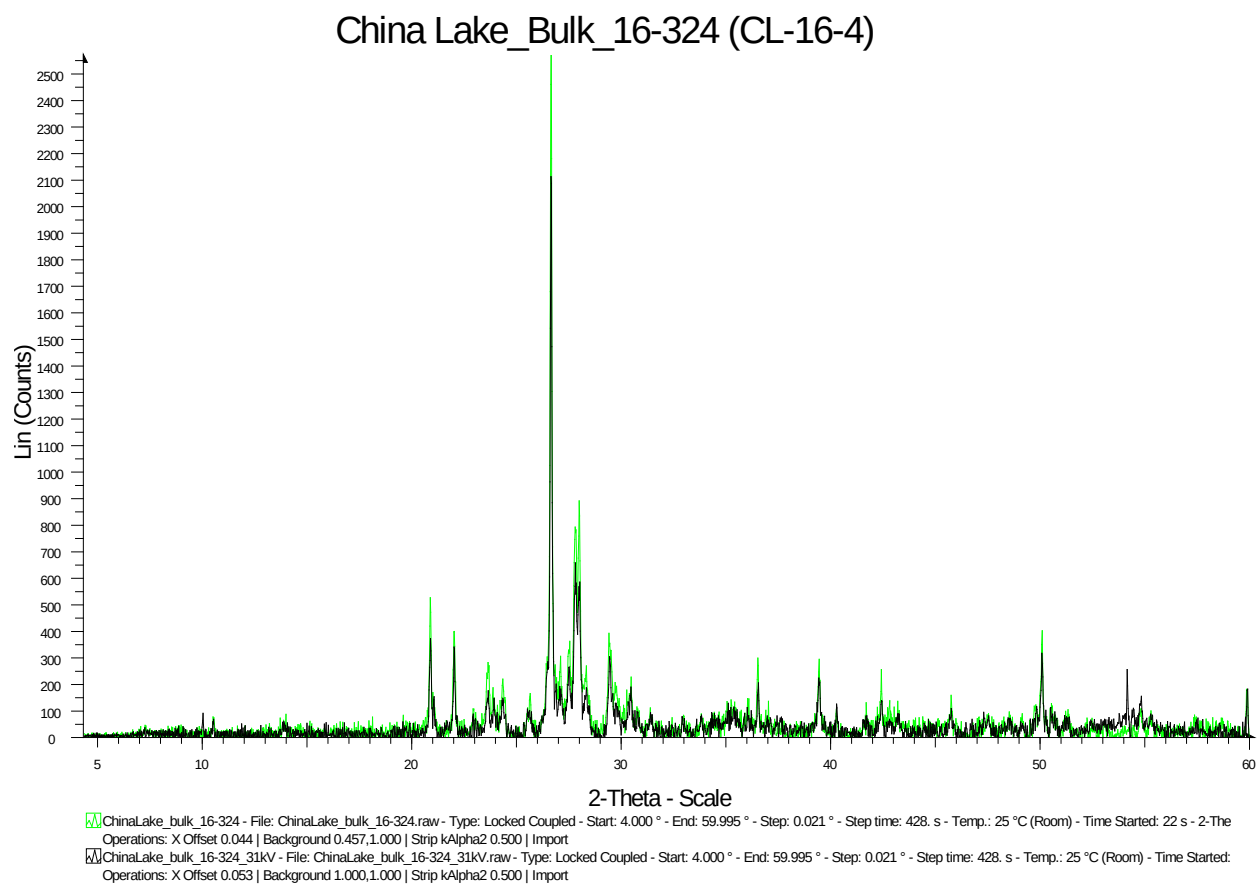


China Lake_Bulk_16-324 (CL-16-4)

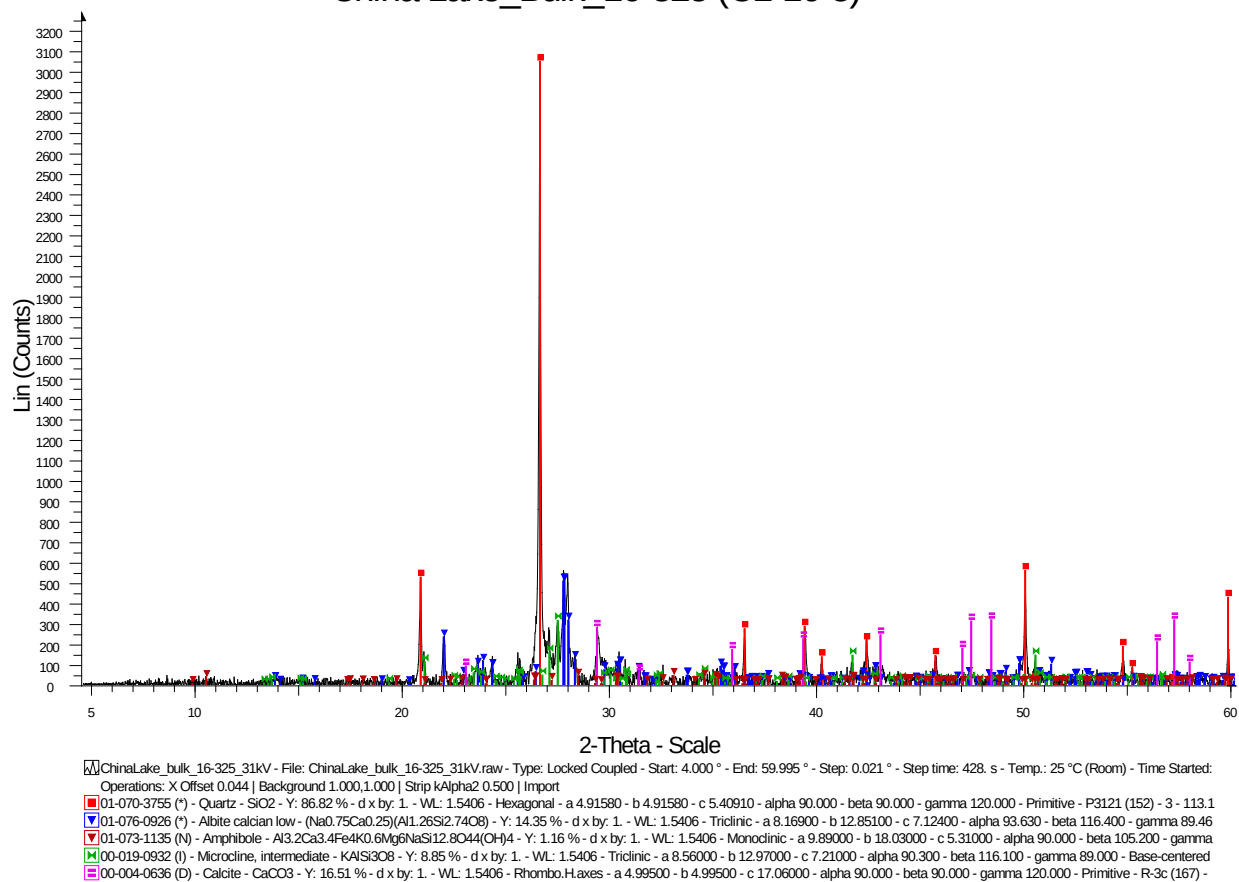


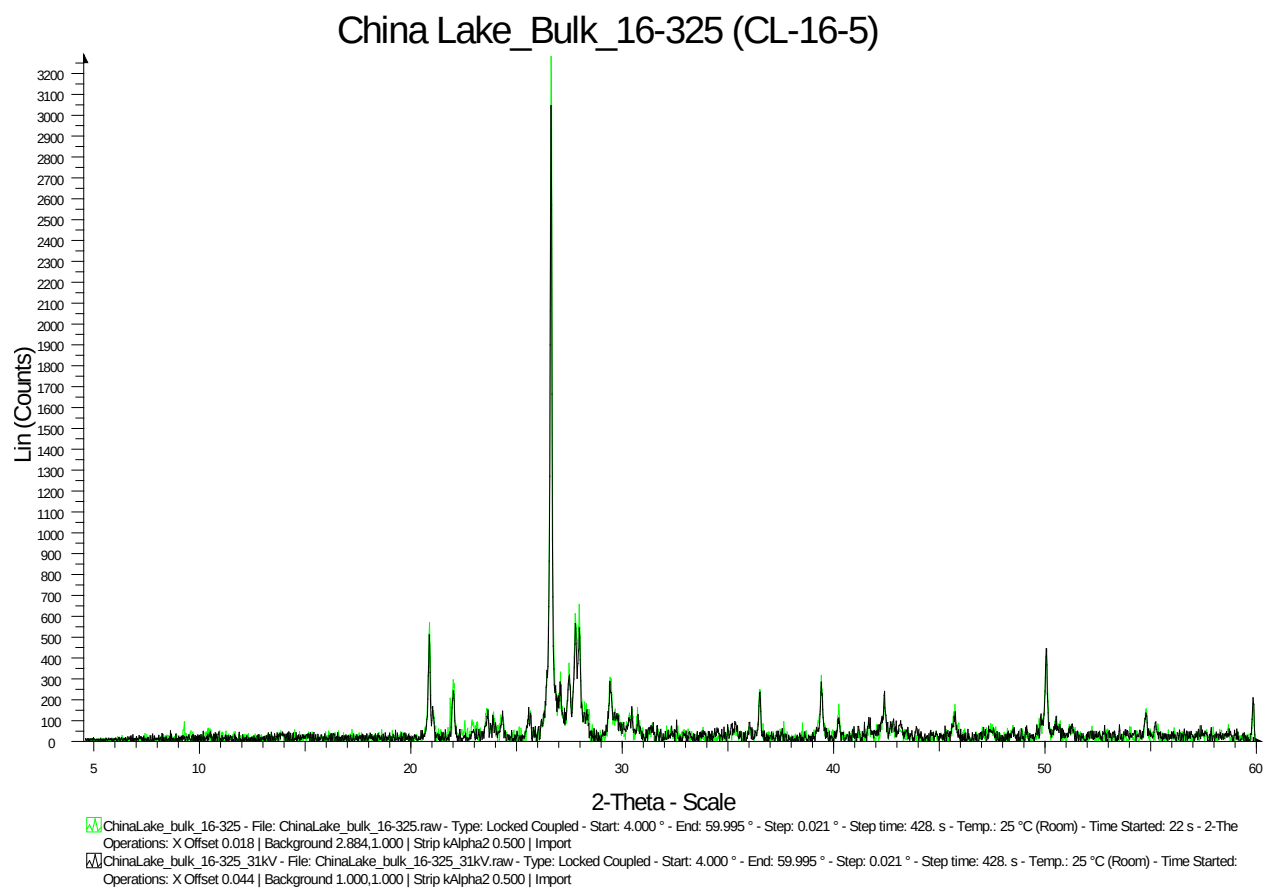
China Lake_Bulk_16-324 (CL-16-4)



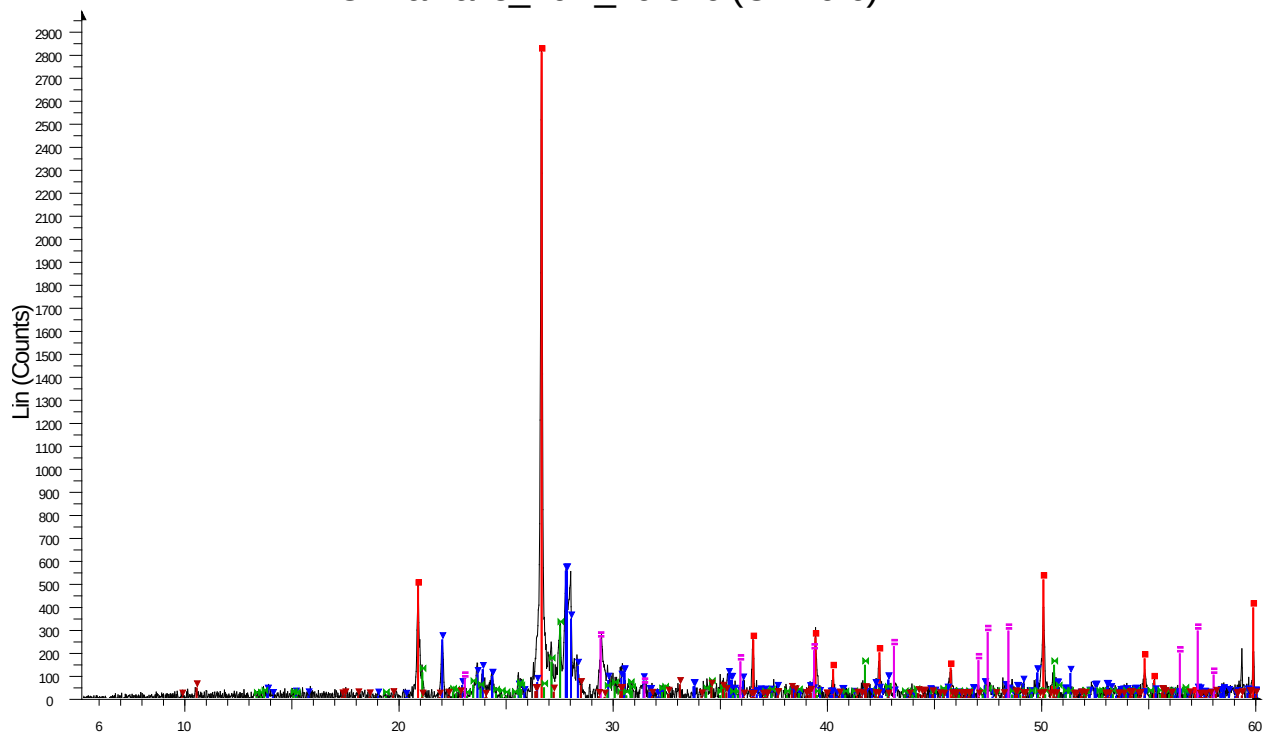


China Lake_Bulk_16-325 (CL-16-5)





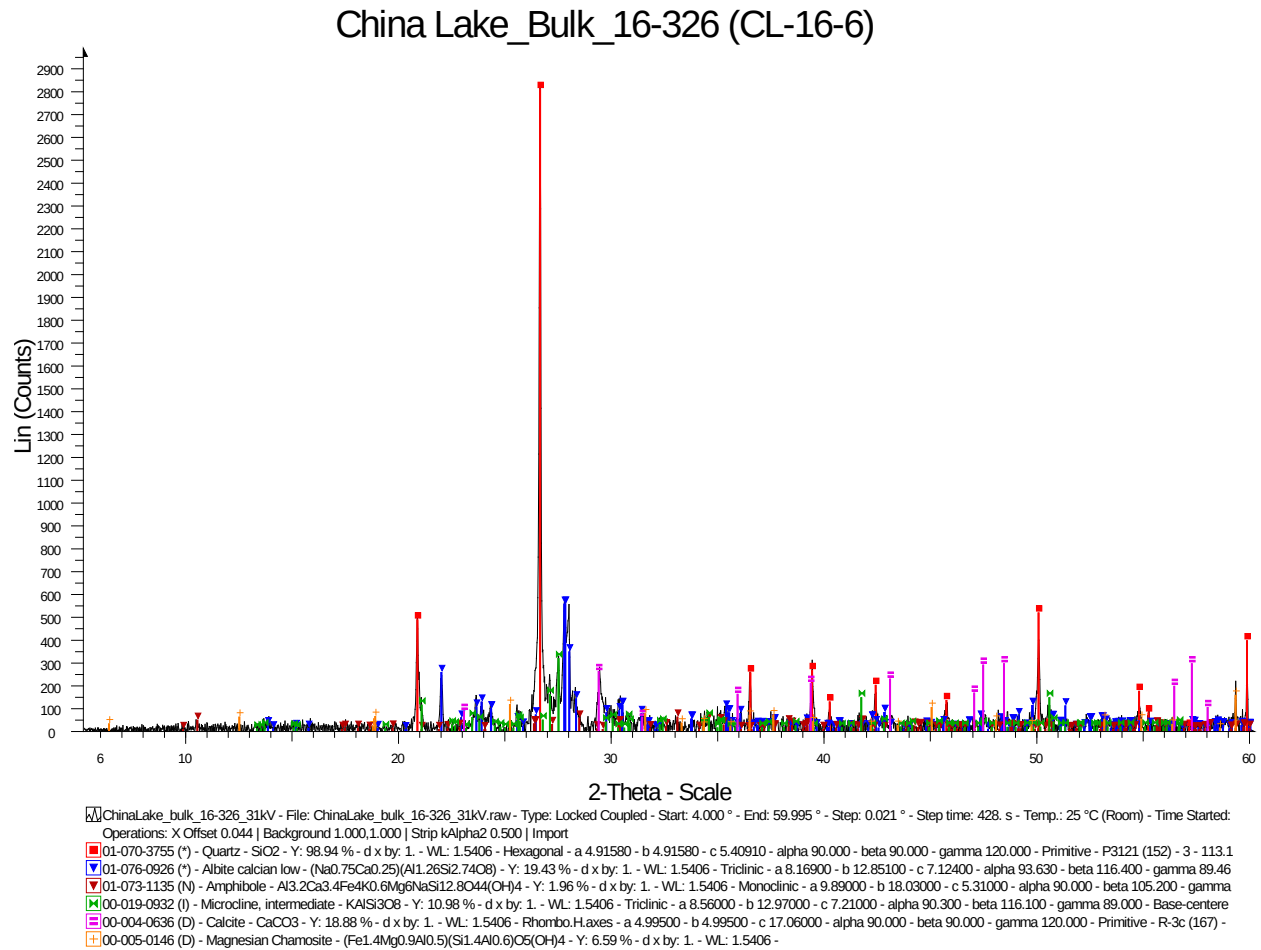
China Lake_Bulk_16-326 (CL-16-6)

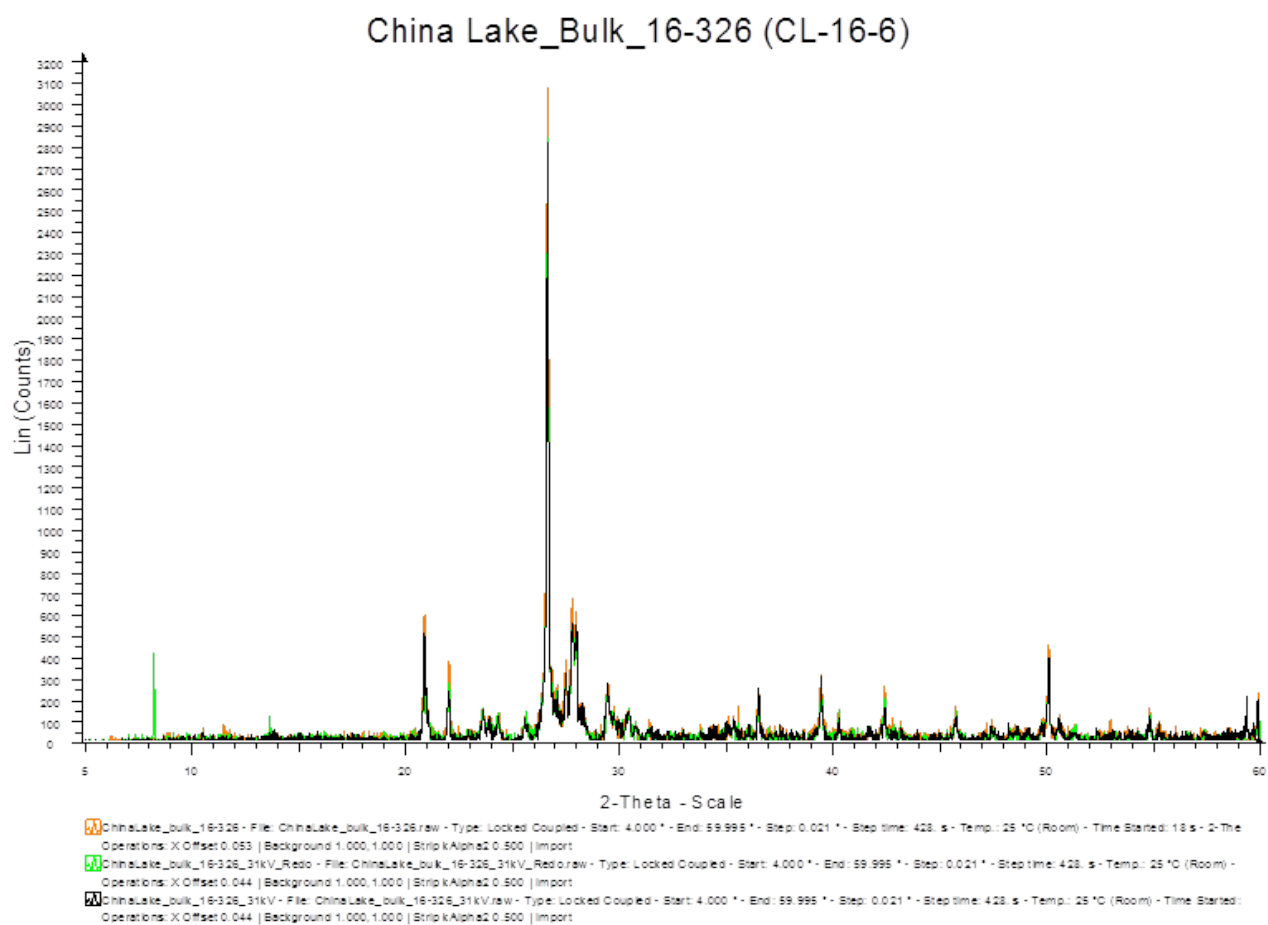


2-Theta - Scale

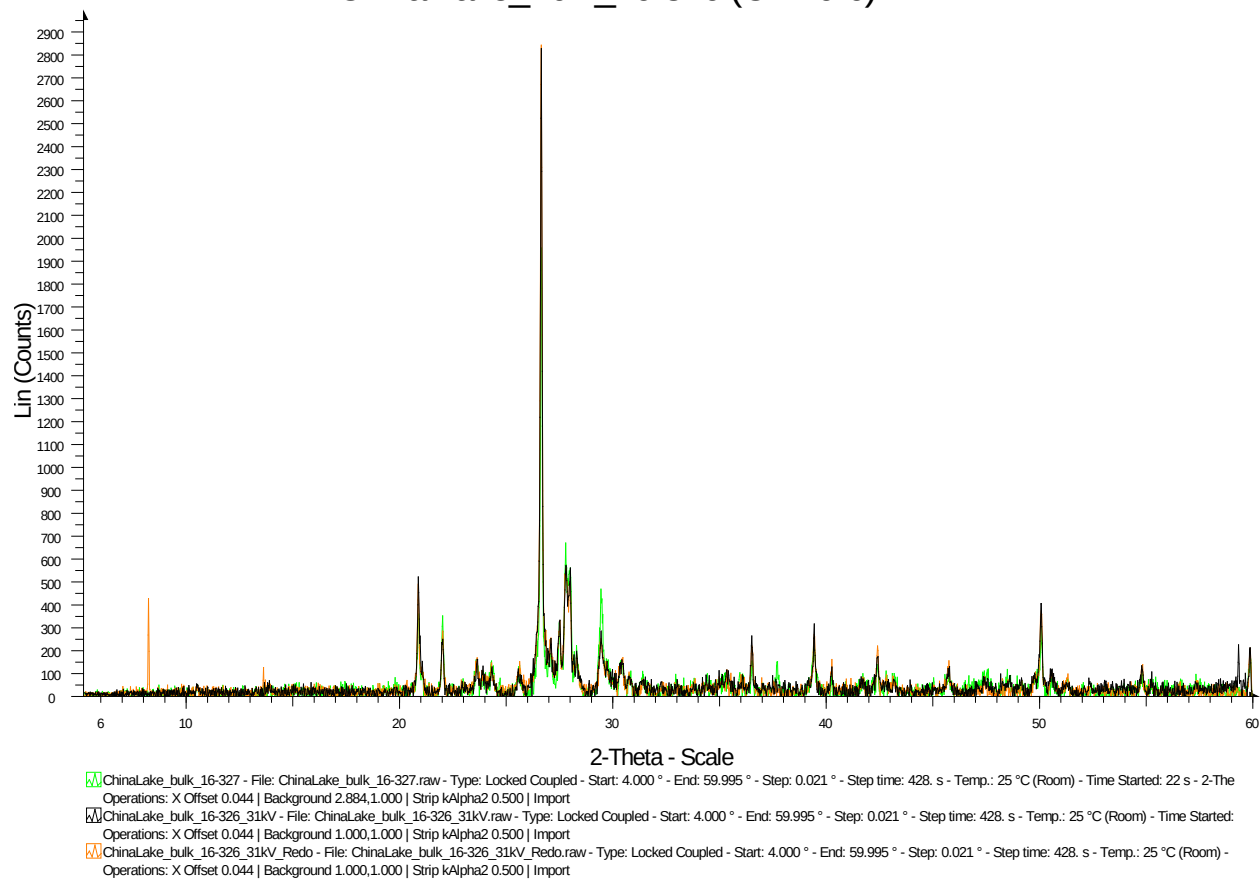
ChinaLake_bulk_16-326_31kV - File: ChinaLake_bulk_16-326_31kV.raw - Type: Locked Coupled - Start: 4.000 ° - End: 59.995 ° - Step: 0.021 ° - Step time: 428. s - Temp.: 25 °C (Room) - Time Started:
 Operations: X Offset 0.044 | Background 1.000,1.000 | Strip kAlpha2 0.500 | Import

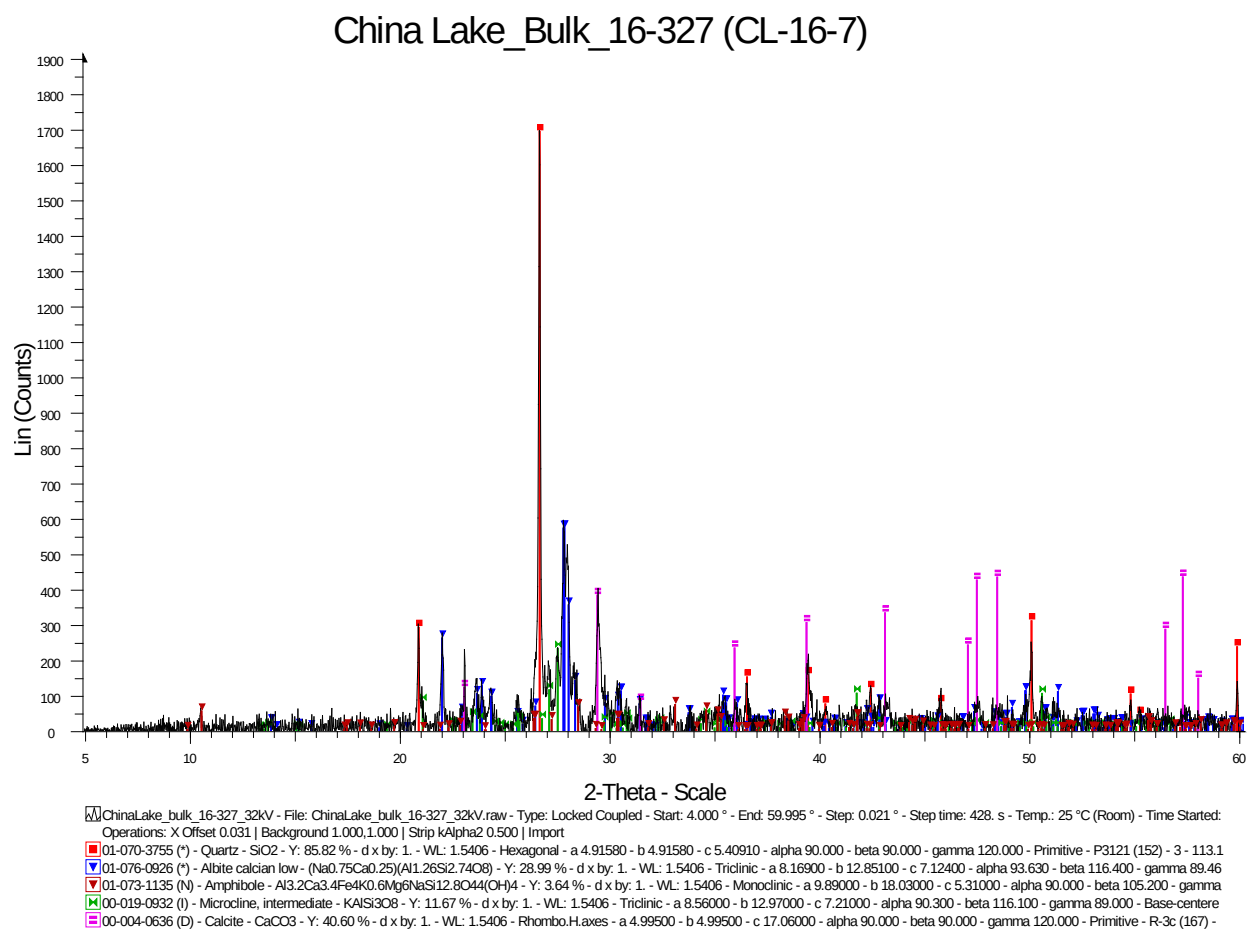
■ 01-070-3755 (*) - Quartz - SiO₂ - Y: 98.94 % - d x by: 1. - WL: 1.5406 - Hexagonal - a 4.91580 - b 4.91580 - c 5.40910 - alpha 90.000 - beta 90.000 - gamma 120.000 - Primitive - P3121 (152) - 3 - 113.1
▼ 01-076-0926 (*) - Albite calcian low - (Na_{0.75}Ca_{0.25})(Al_{1.26}Si_{2.74}O₈) - Y: 19.43 % - d x by: 1. - WL: 1.5406 - Triclinic - a 8.16900 - b 12.85100 - c 7.12400 - alpha 93.630 - beta 116.400 - gamma 89.46
▼ 01-073-1135 (N) - Amphibole - Al_{3.2}Ca_{3.4}Fe₄K_{0.6}Mg₆NaSi_{12.8}O₄₄(OH)₄ - Y: 1.96 % - d x by: 1. - WL: 1.5406 - Monoclinic - a 9.89000 - b 18.03000 - c 5.31000 - alpha 90.000 - beta 105.200 - gamma
■ 00-019-0932 (I) - Microcline, intermediate - KAlSi₃O₈ - Y: 10.98 % - d x by: 1. - WL: 1.5406 - Triclinic - a 8.56000 - b 12.97000 - c 7.21000 - alpha 90.300 - beta 116.100 - gamma 89.000 - Base-center
■ 00-004-0636 (D) - Calcite - CaCO₃ - Y: 18.88 % - d x by: 1. - WL: 1.5406 - Rhombo.H.axes - a 4.99500 - b 4.99500 - c 17.06000 - alpha 90.000 - beta 90.000 - gamma 120.000 - Primitive - R-3c (167) -

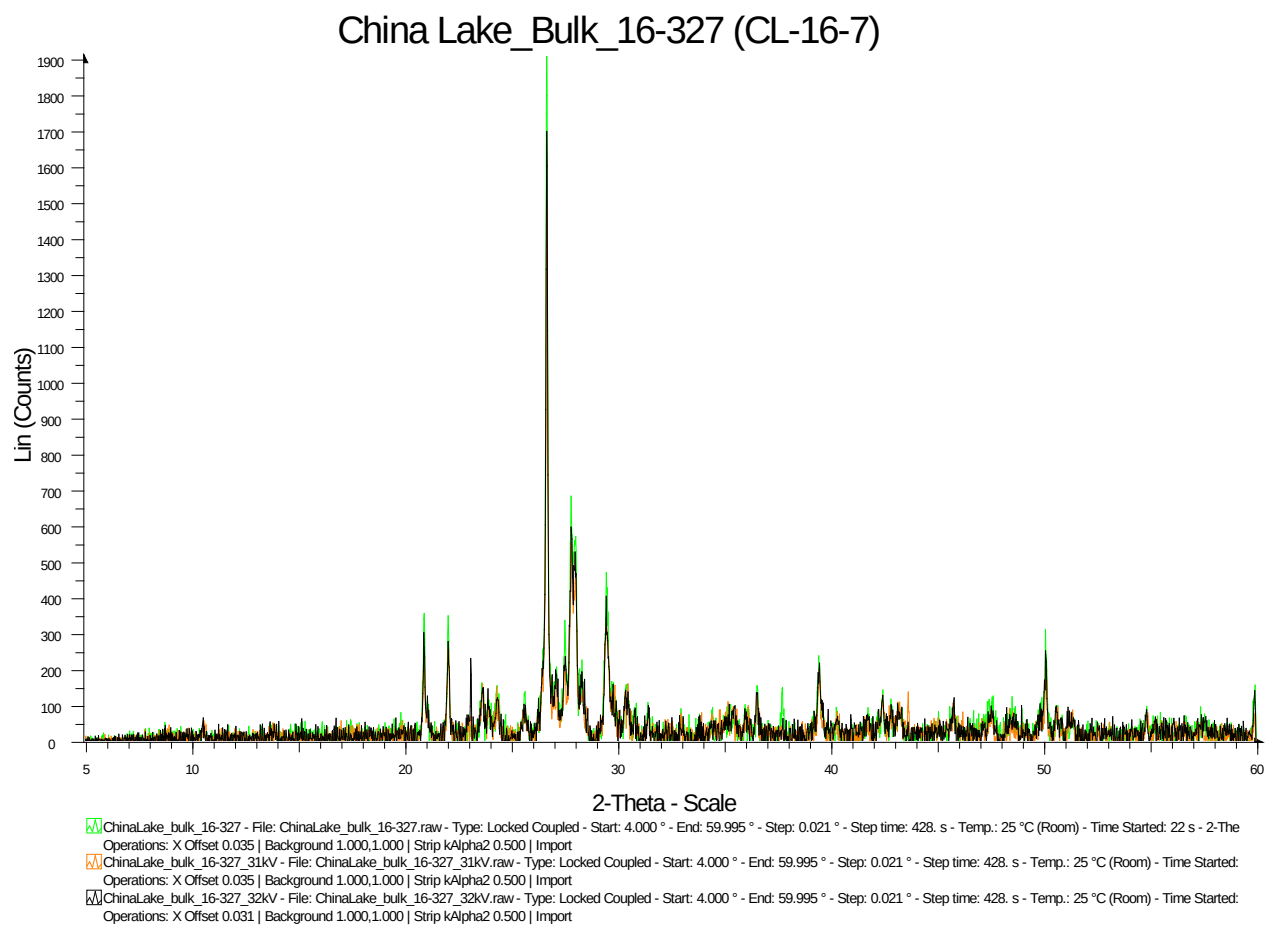




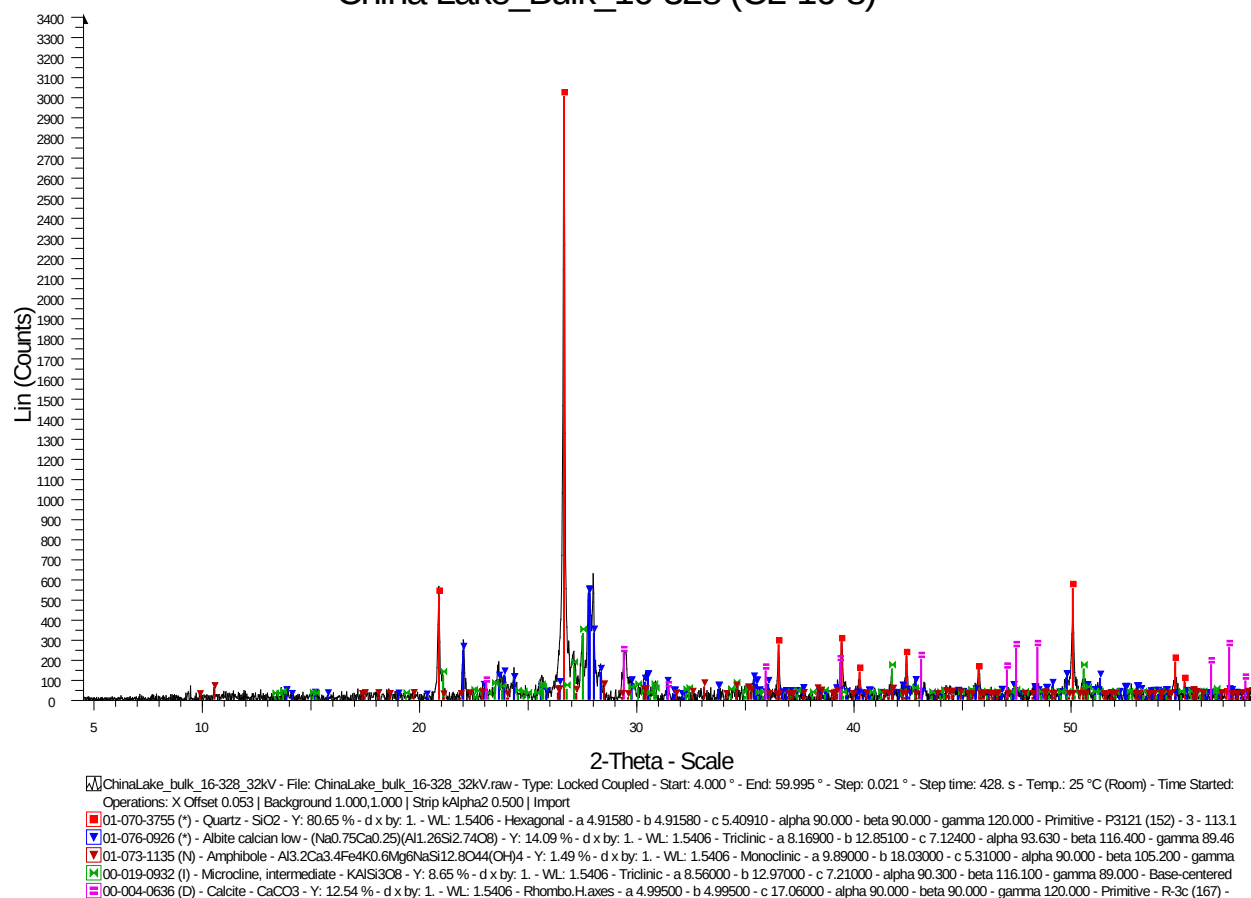
China Lake_Bulk_16-326 (CL-16-6)

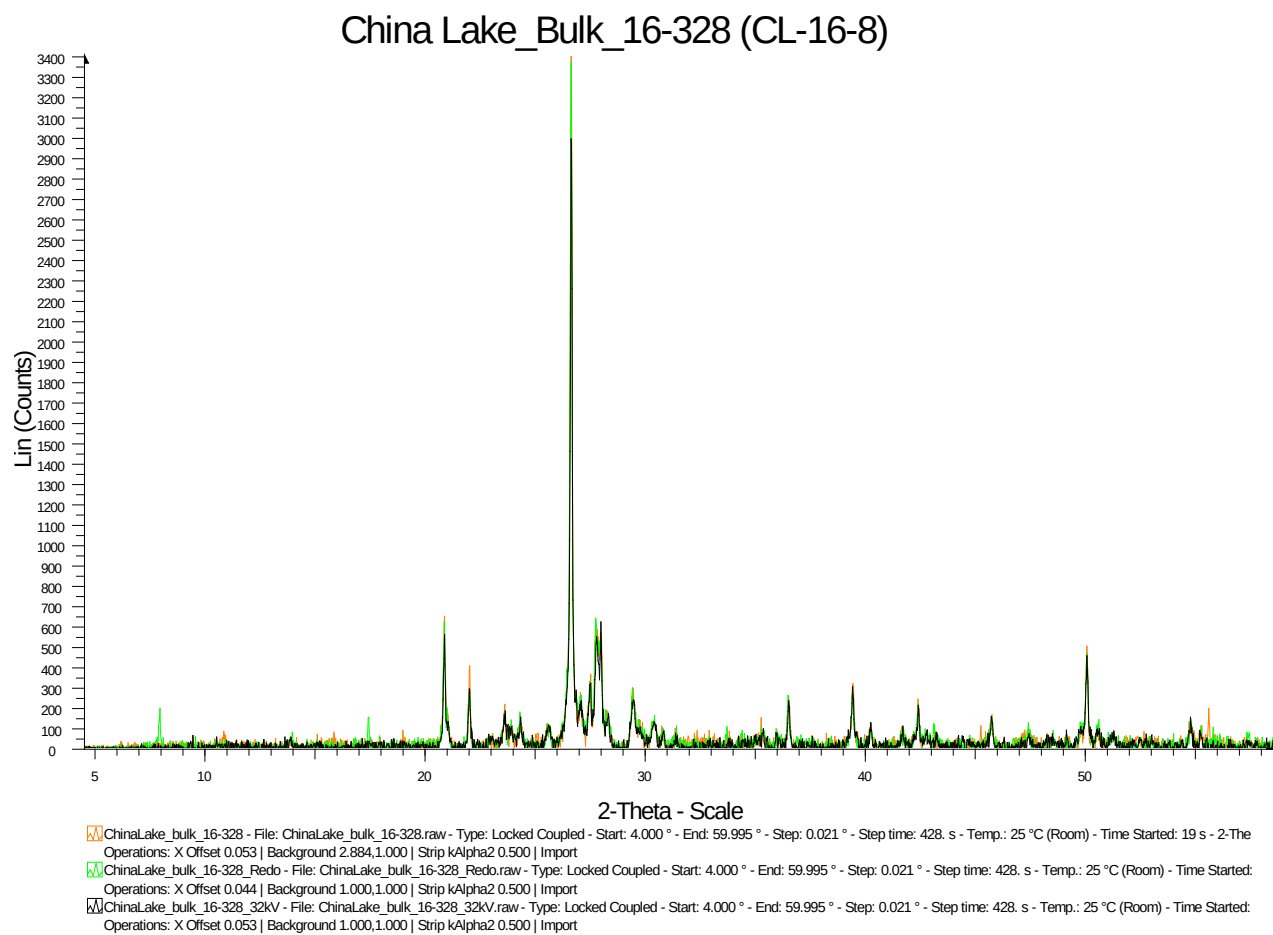




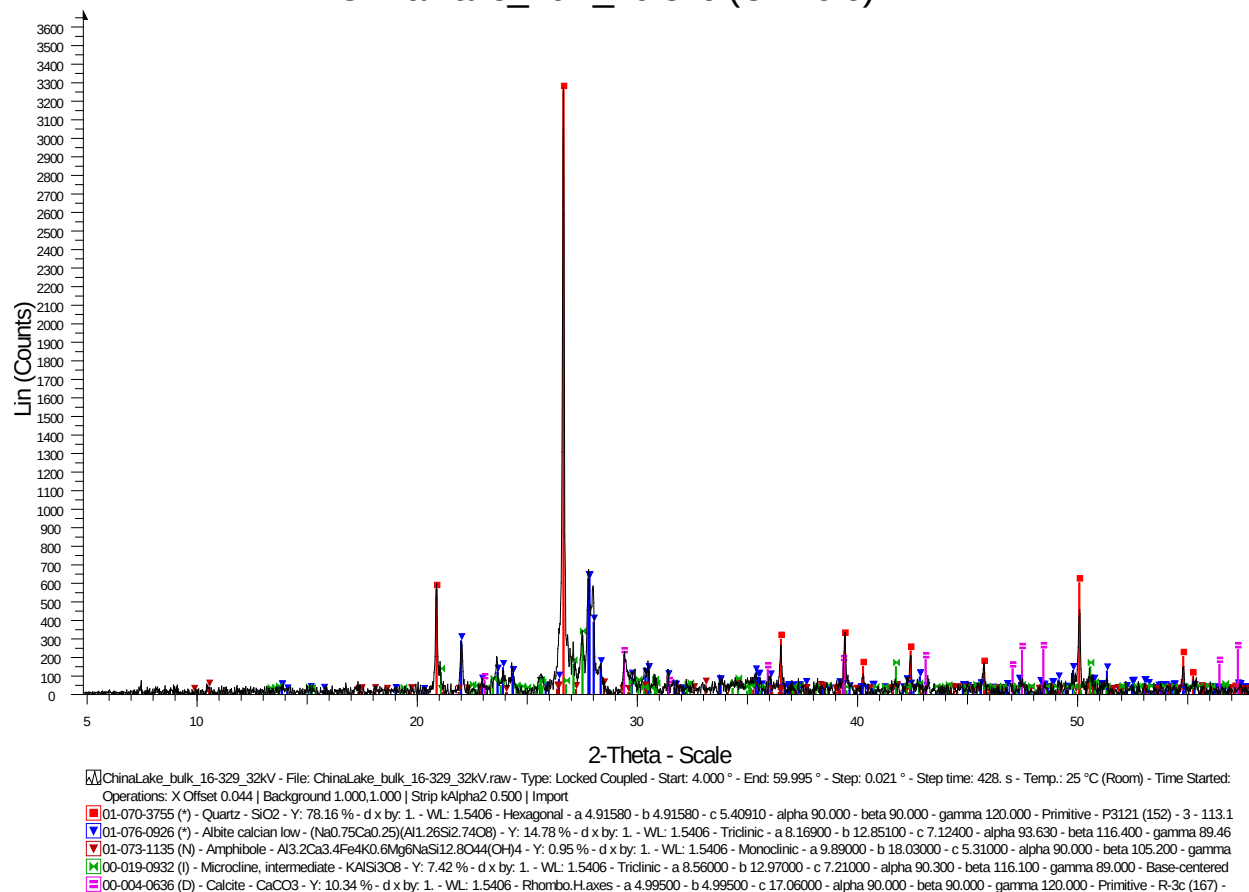


China Lake_Bulk_16-328 (CL-16-8)

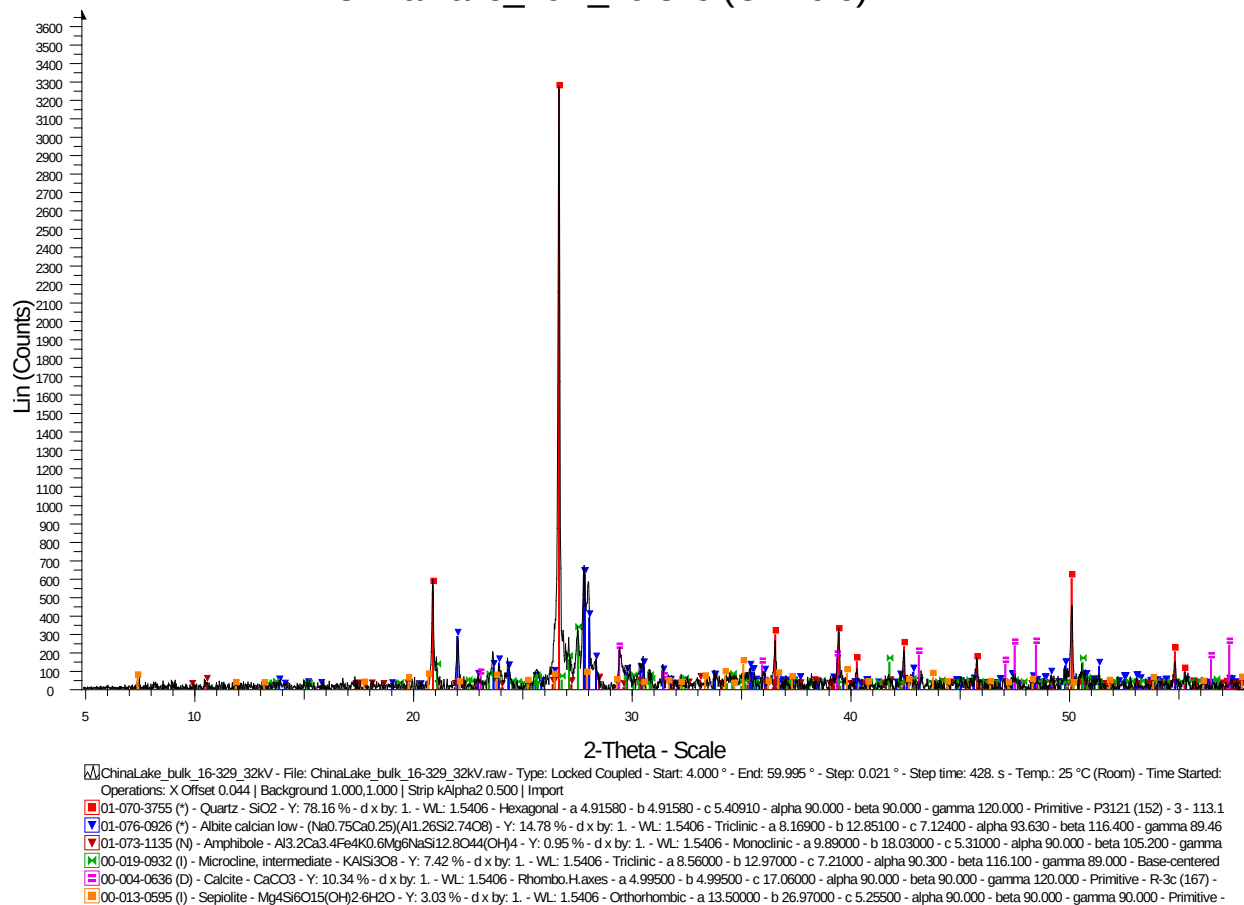


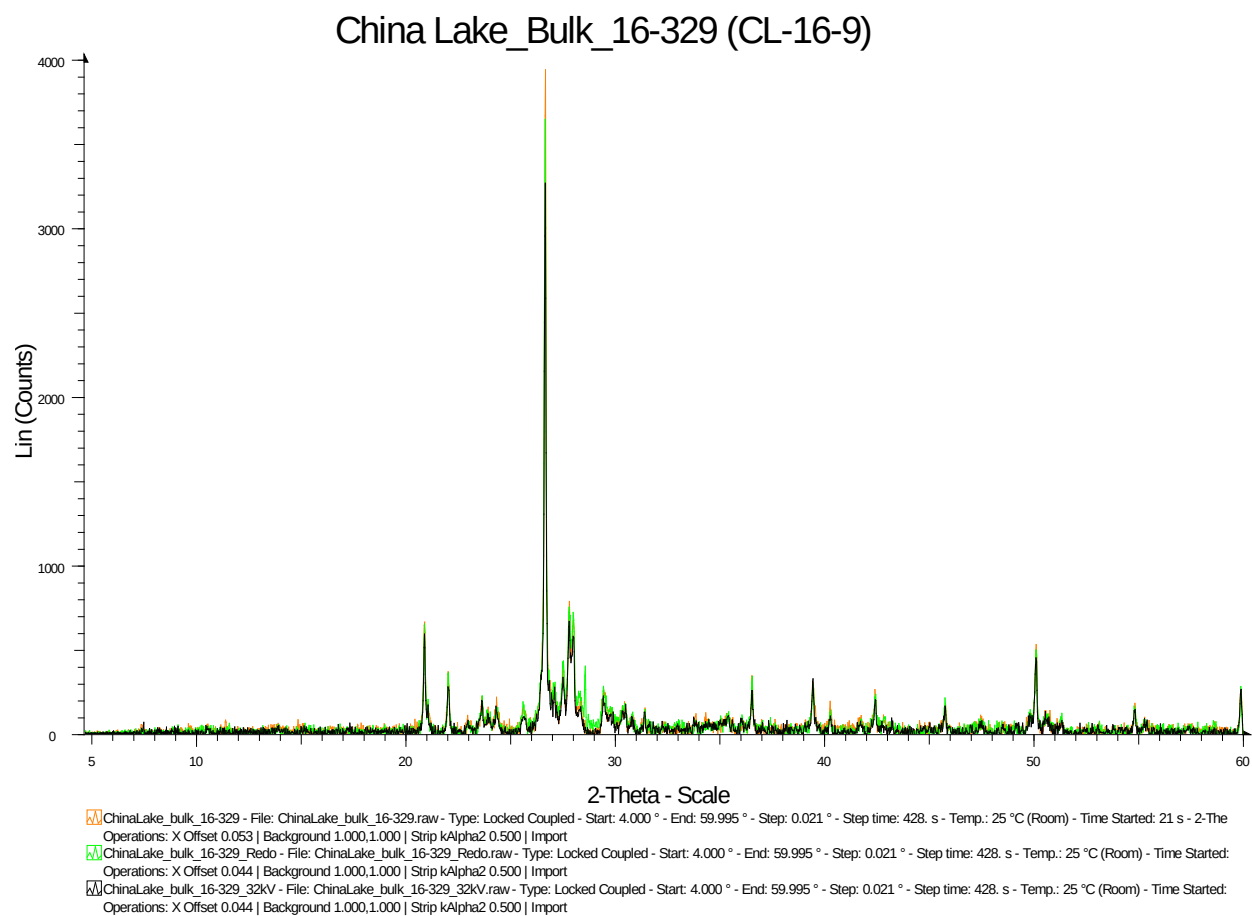


China Lake_Bulk_16-329 (CL-16-9)

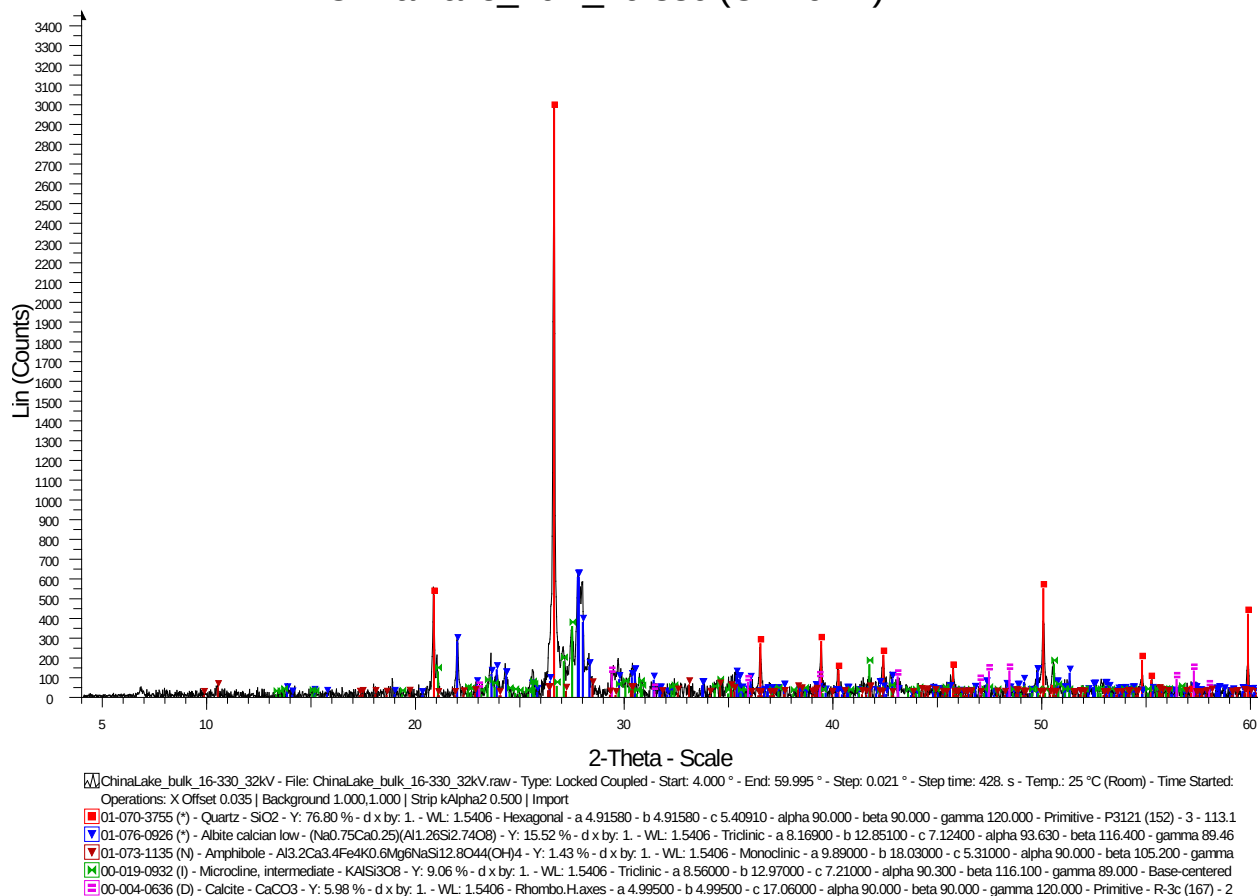


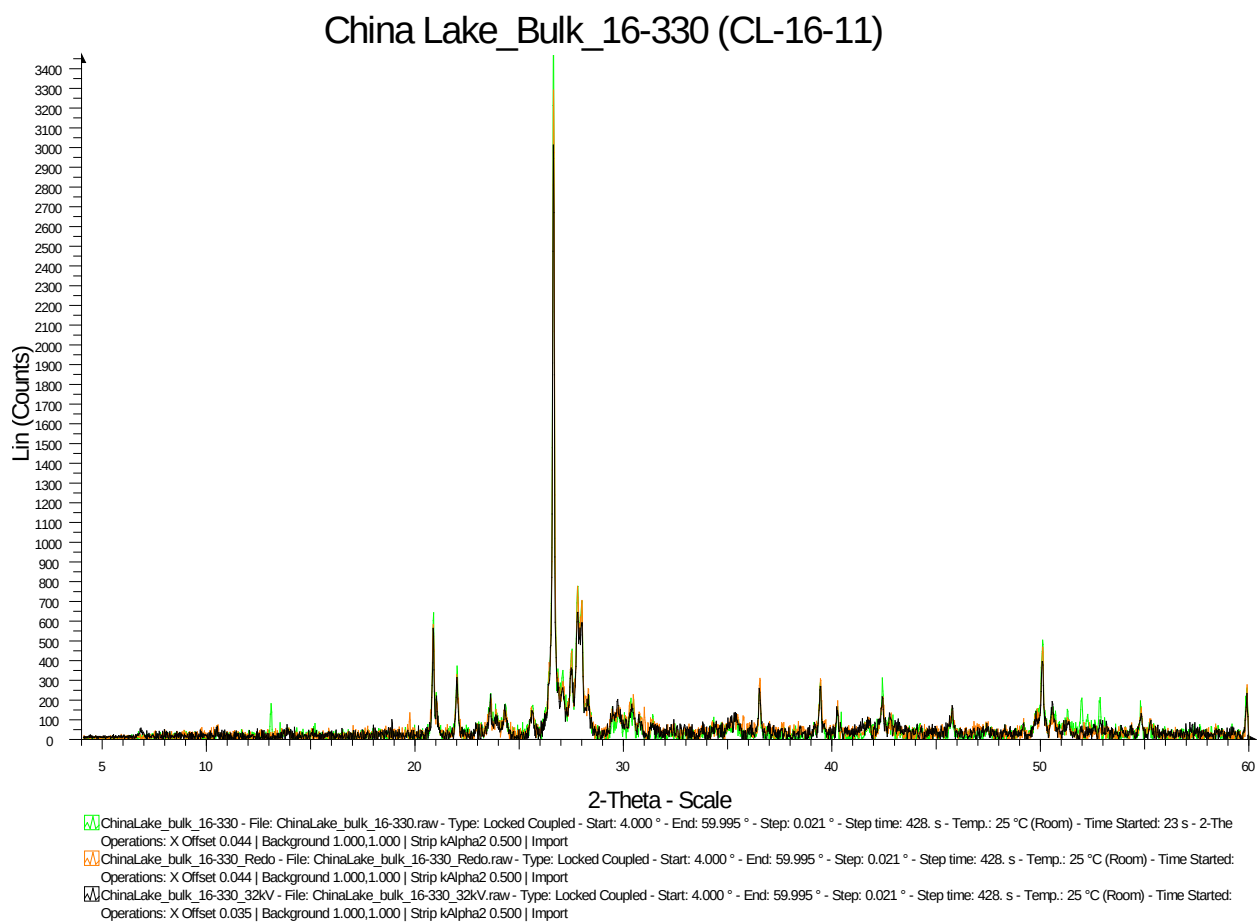
China Lake_Bulk_16-329 (CL-16-9)



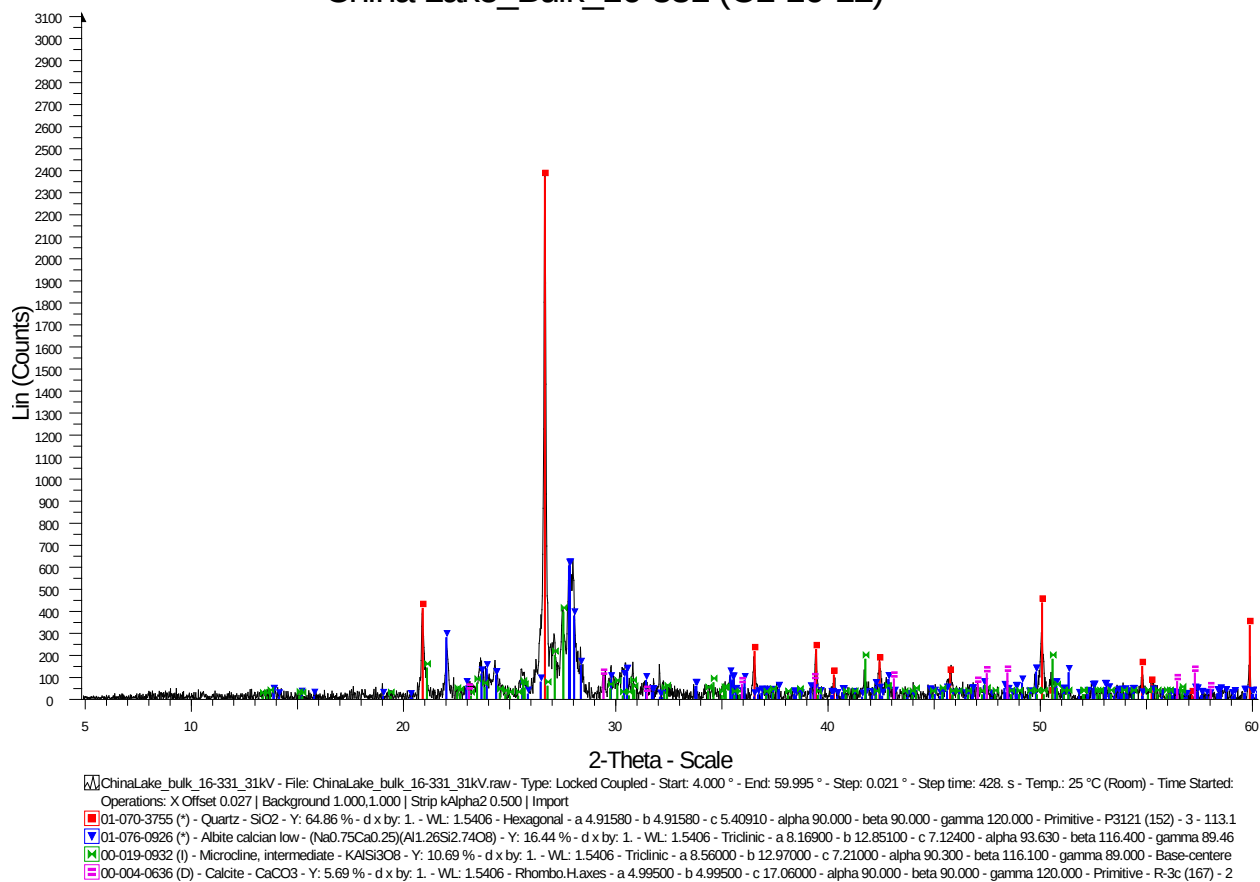


China Lake_Bulk_16-330 (CL-16-11)

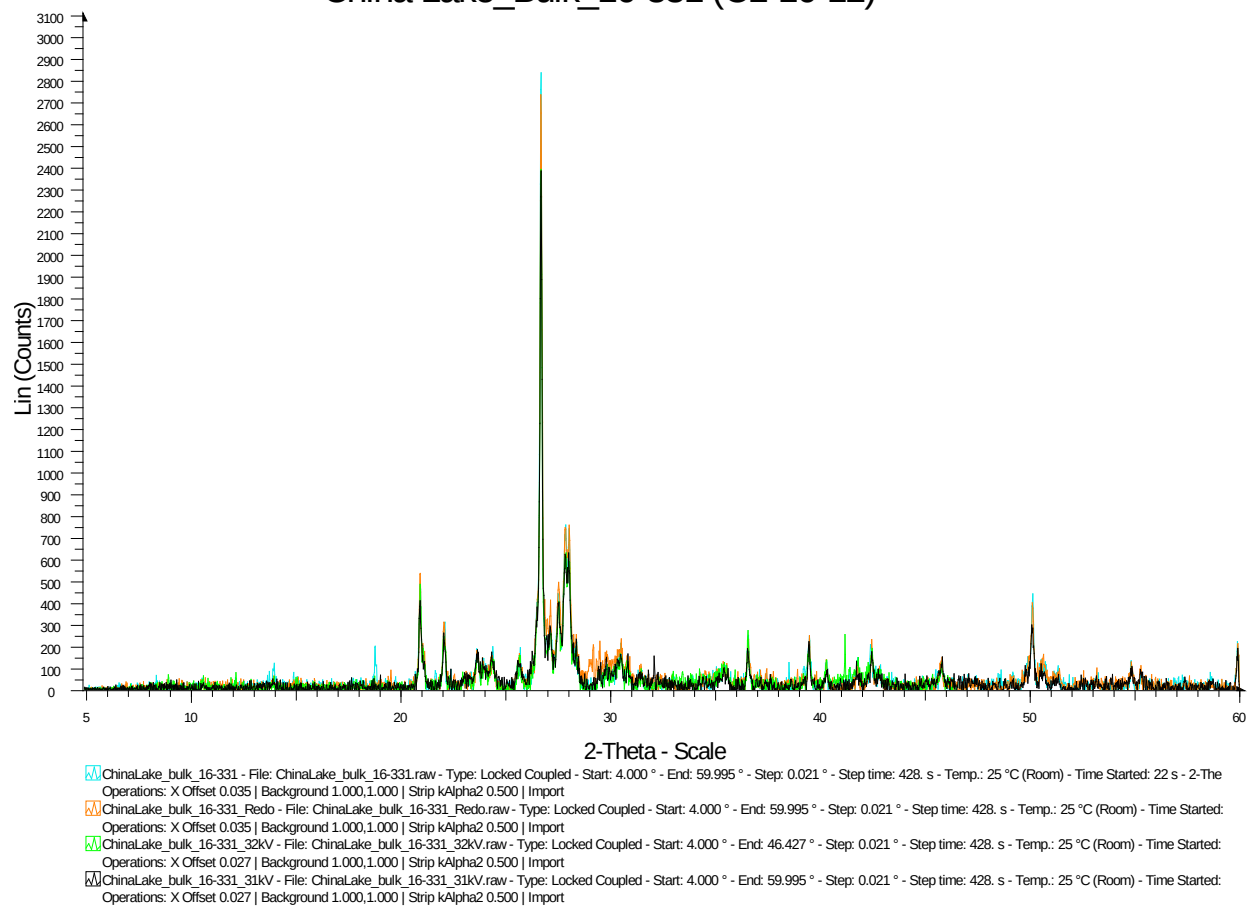




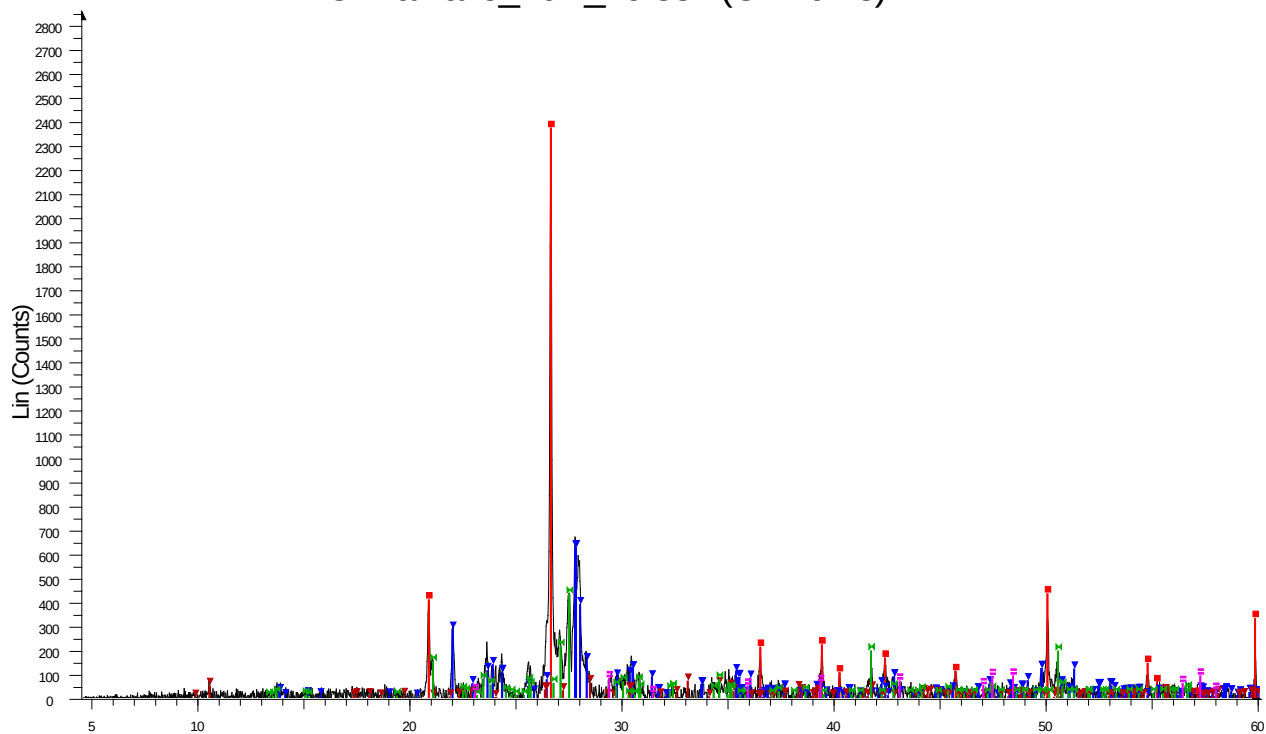
China Lake_Bulk_16-331 (CL-16-12)



China Lake_Bulk_16-331 (CL-16-12)



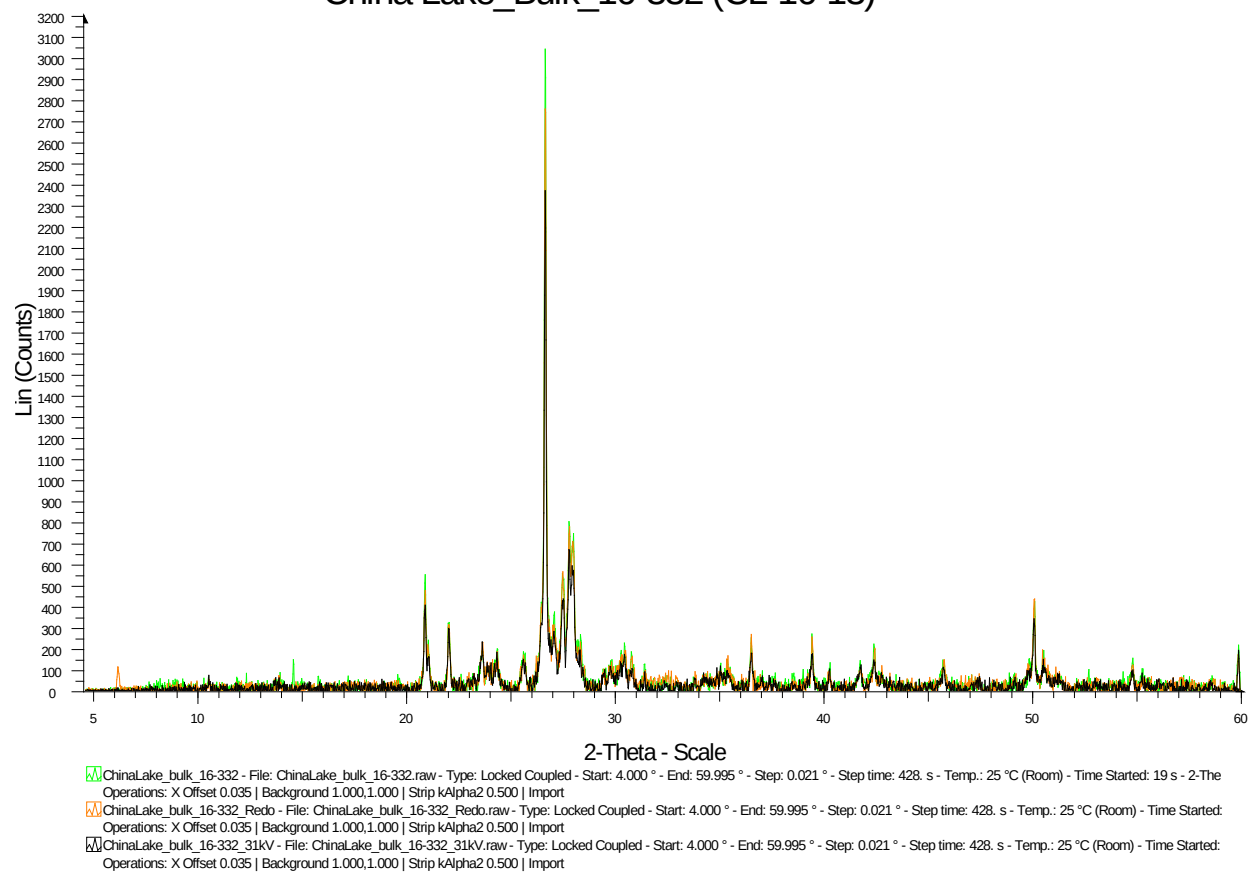
China Lake_Bulk_16-332 (CL-16-13)



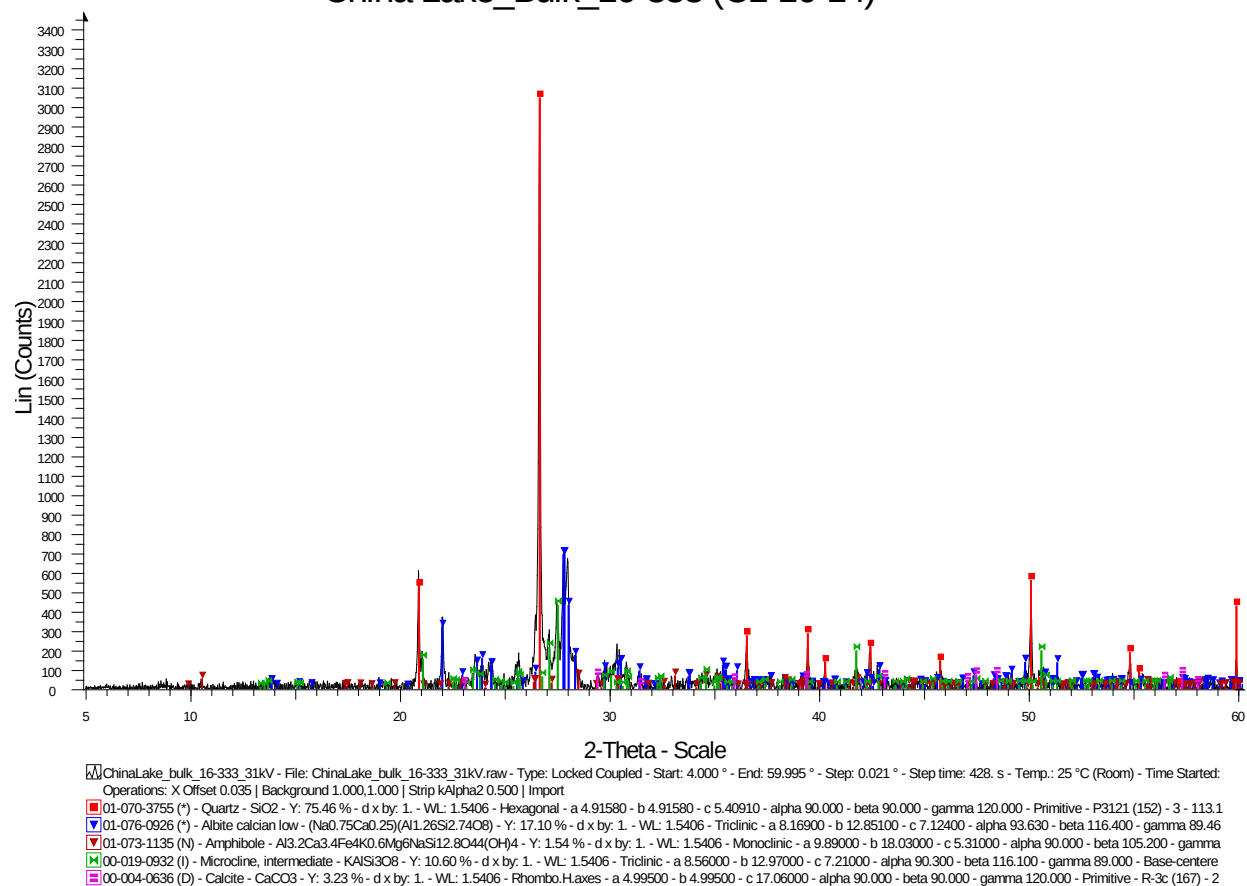
ChinaLake_bulk_16-332_31kV - File: ChinaLake_bulk_16-332_31kV.raw - Type: Locked Coupled - Start: 4.000 ° - End: 59.995 ° - Step: 0.021 ° - Step time: 428. s - Temp.: 25 °C (Room) - Time Started:
 Operations: X Offset 0.035 | Background 1.000,1.000 | Strip kAlpha2 0.500 | Import

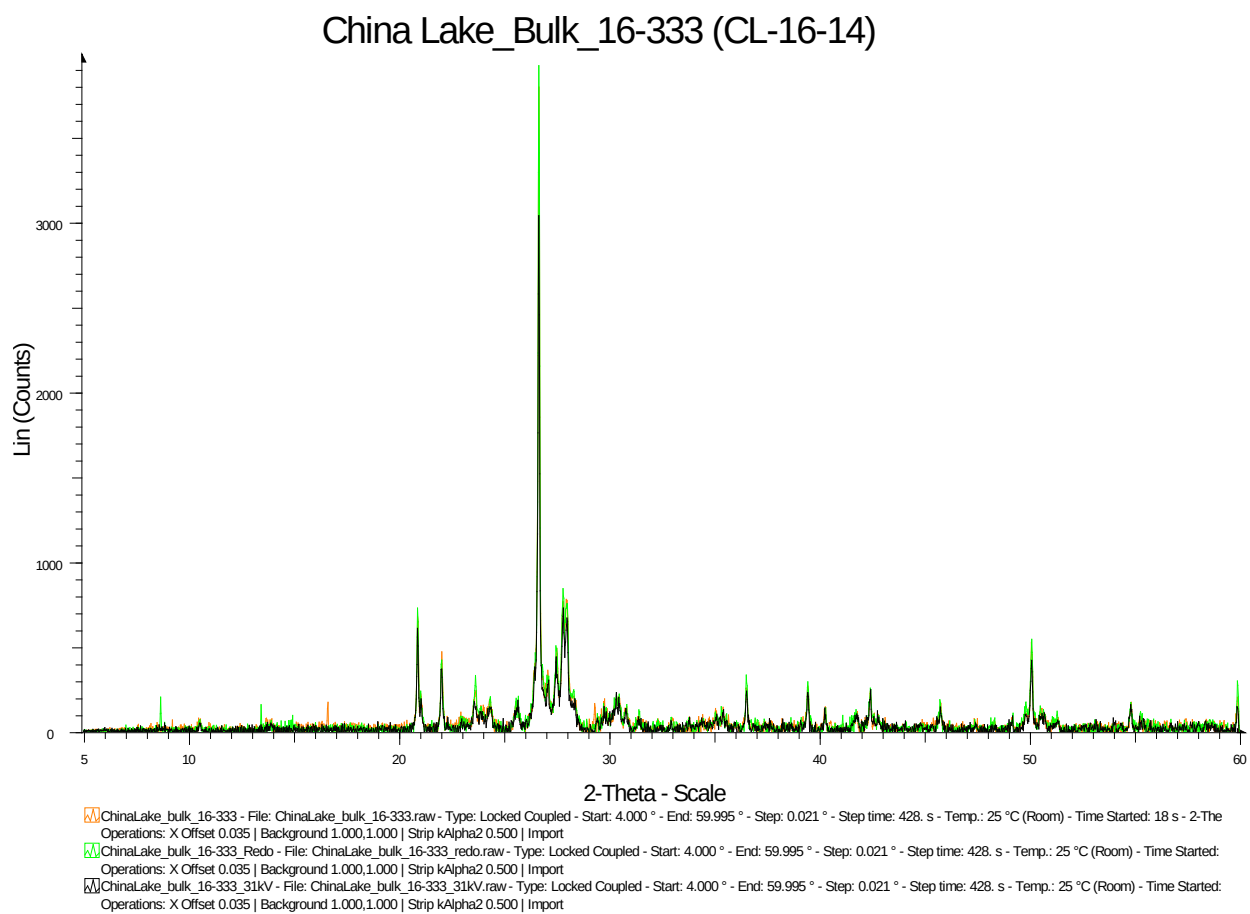
01-070-3755 (*) - Quartz - SiO₂ - Y: 72.52 % - d x by: 1. - WL: 1.5406 - Hexagonal - a 4.91580 - b 4.91580 - c 5.40910 - alpha 90.000 - beta 90.000 - gamma 120.000 - Primitive - P3121 (152) - 3 - 113.1
 01-076-0926 (*) - Albite calcian low - (Na_{0.75}Ca_{0.25})(Al_{1.26}Si_{2.74}O₈) - Y: 19.11 % - d x by: 1. - WL: 1.5406 - Triclinic - a 8.16900 - b 12.85100 - c 7.12400 - alpha 93.630 - beta 116.400 - gamma 89.46
 01-073-1135 (N) - Amphibole - Al_{3.2}Ca_{3.4}Fe₄K_{0.6}Mg₆NaSi_{12.8}O₄₄(OH)₄ - Y: 2.08 % - d x by: 1. - WL: 1.5406 - Monoclinic - a 9.89000 - b 18.03000 - c 5.31000 - alpha 90.000 - beta 105.200 - gamma
 00-019-0932 (I) - Microcline, intermediate - KAlSi₃O₈ - Y: 13.14 % - d x by: 1. - WL: 1.5406 - Triclinic - a 8.56000 - b 12.97000 - c 7.21000 - alpha 90.300 - beta 116.100 - gamma 89.000 - Base-center
 00-004-0636 (D) - Calcite - CaCO₃ - Y: 5.08 % - d x by: 1. - WL: 1.5406 - Rhombo.H.axes - a 4.99500 - b 4.99500 - c 17.06000 - alpha 90.000 - beta 90.000 - gamma 120.000 - Primitive - R-3c (167) - 2

China Lake_Bulk_16-332 (CL-16-13)

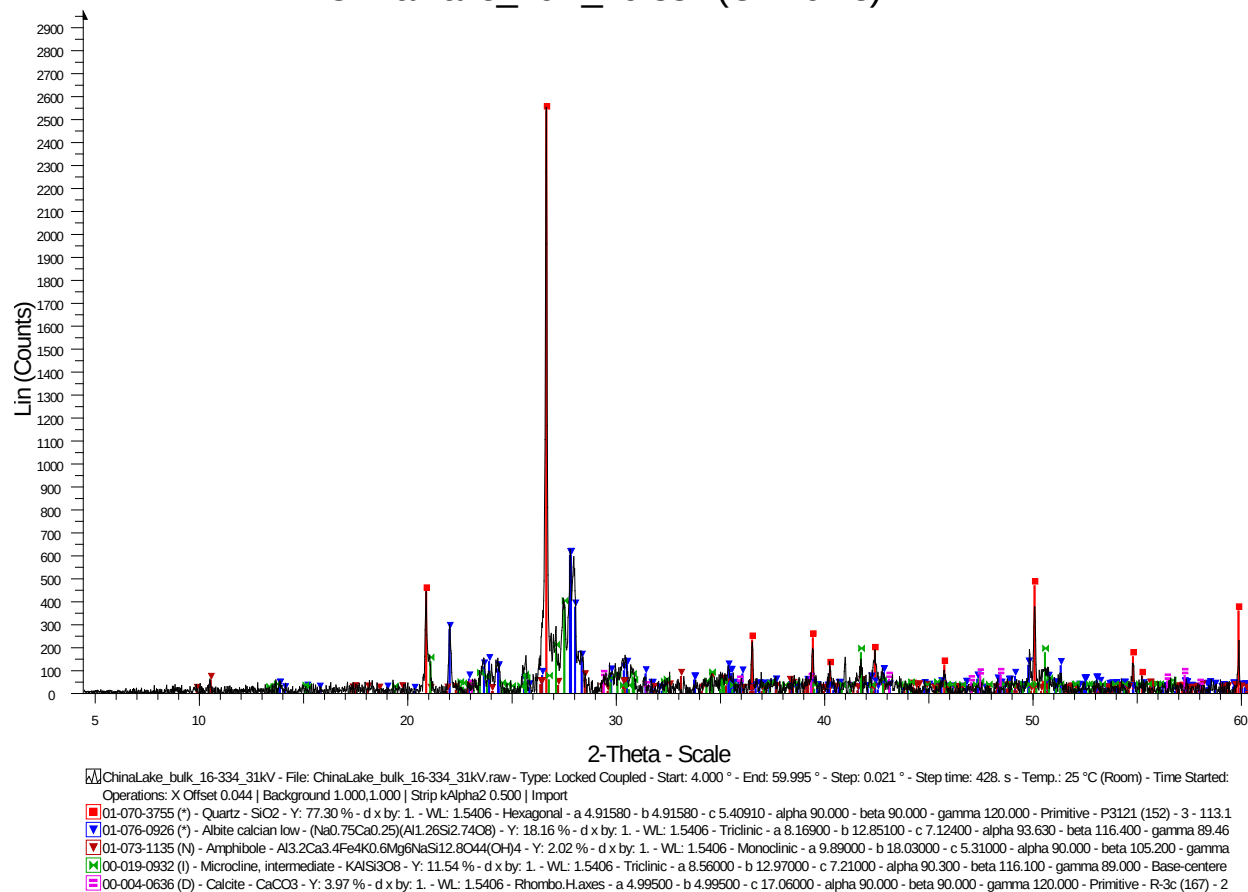


China Lake_Bulk_16-333 (CL-16-14)

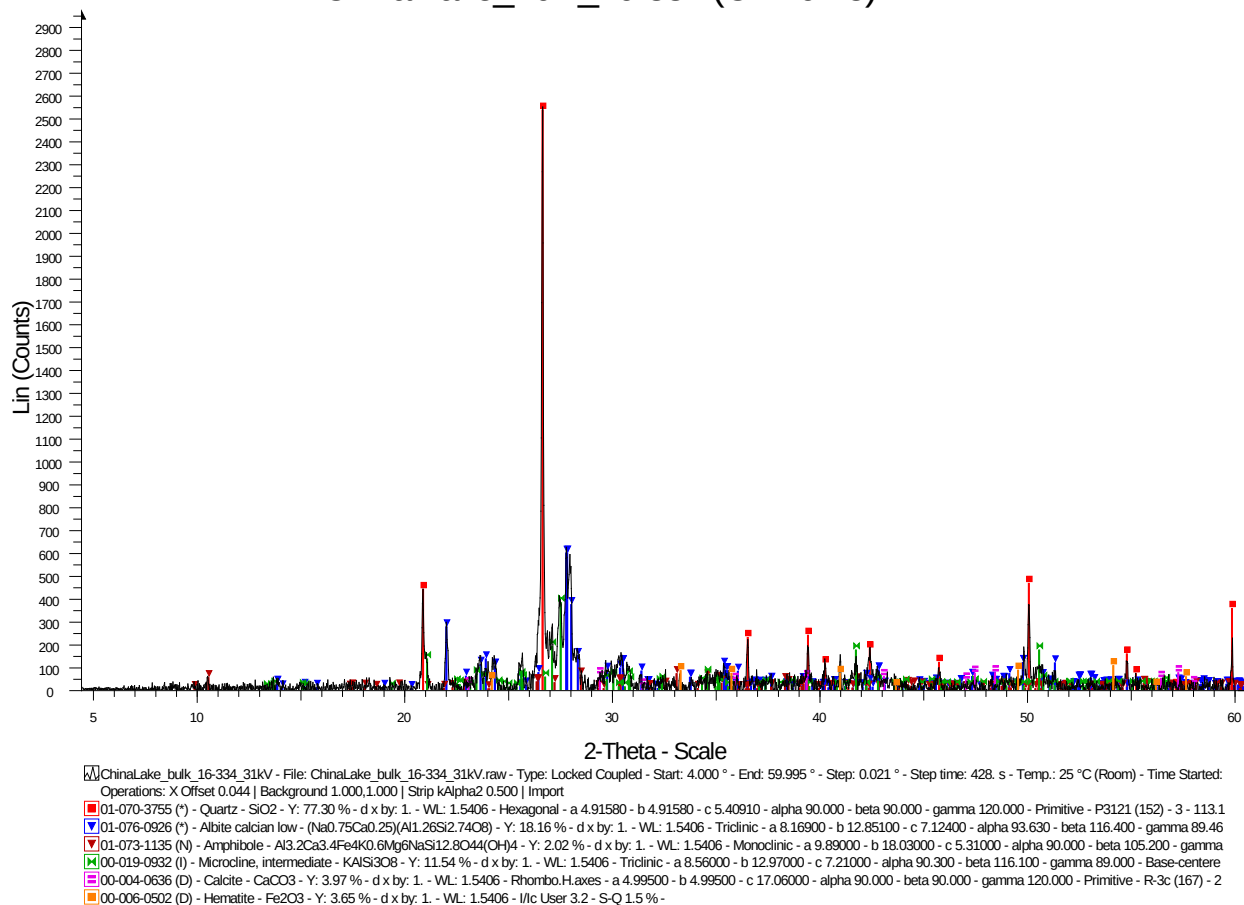




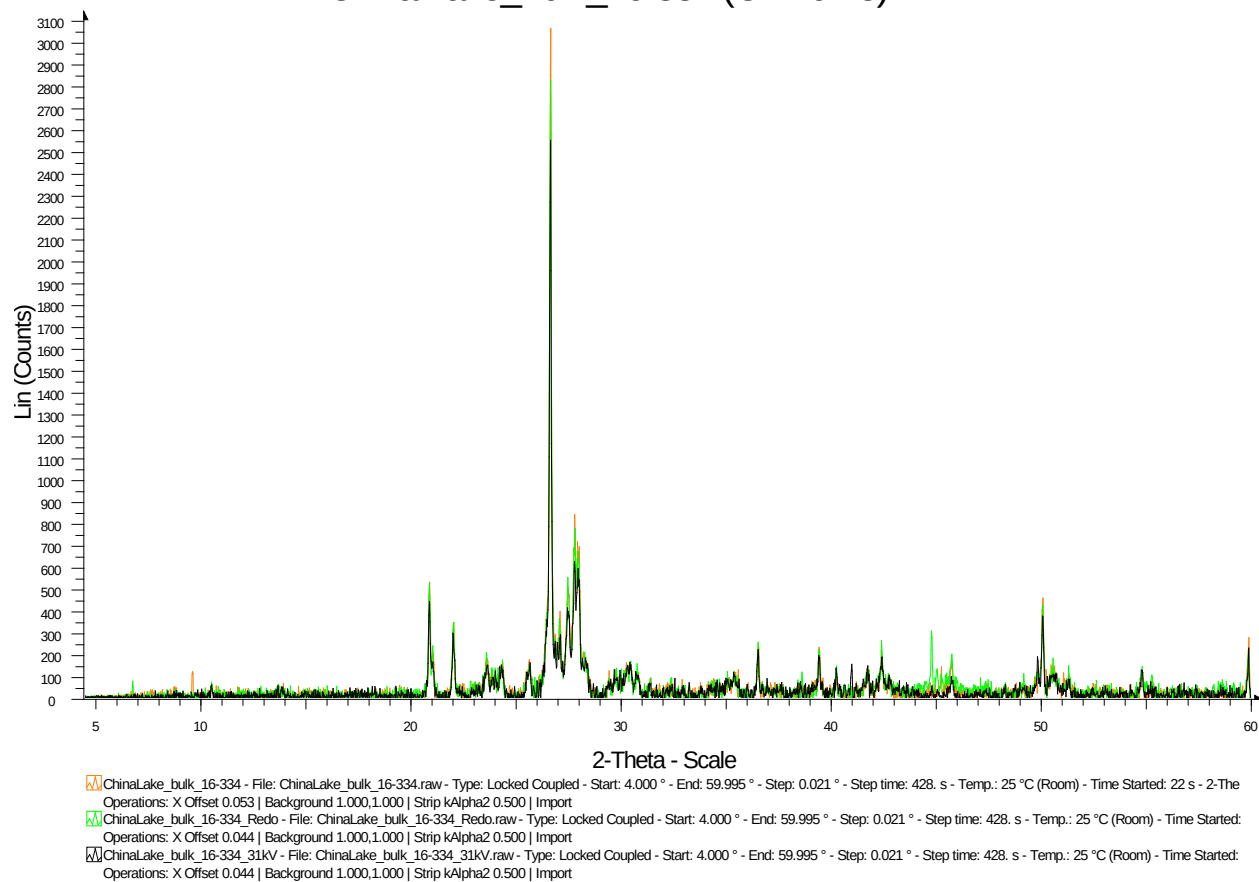
China Lake_Bulk_16-334 (CL-16-15)



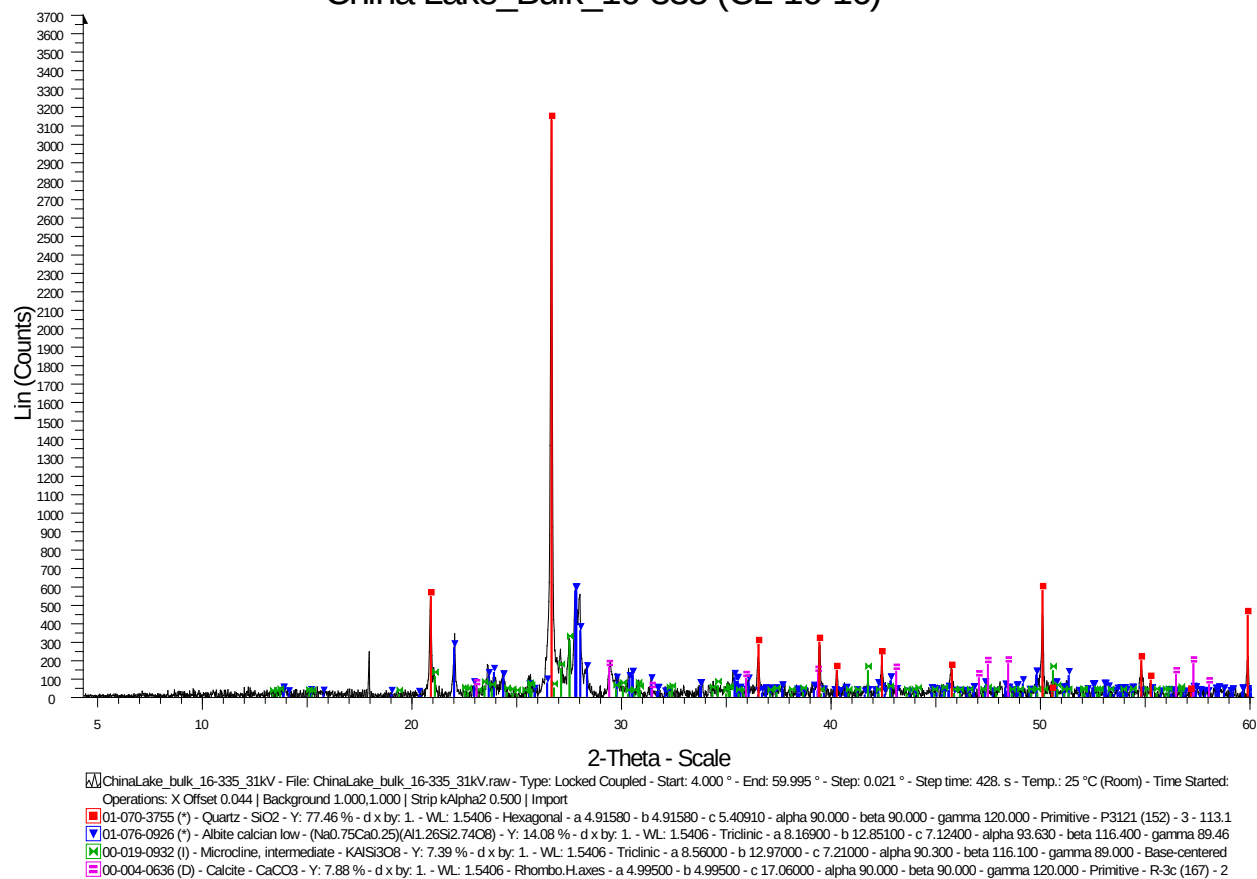
China Lake_Bulk_16-334 (CL-16-15)



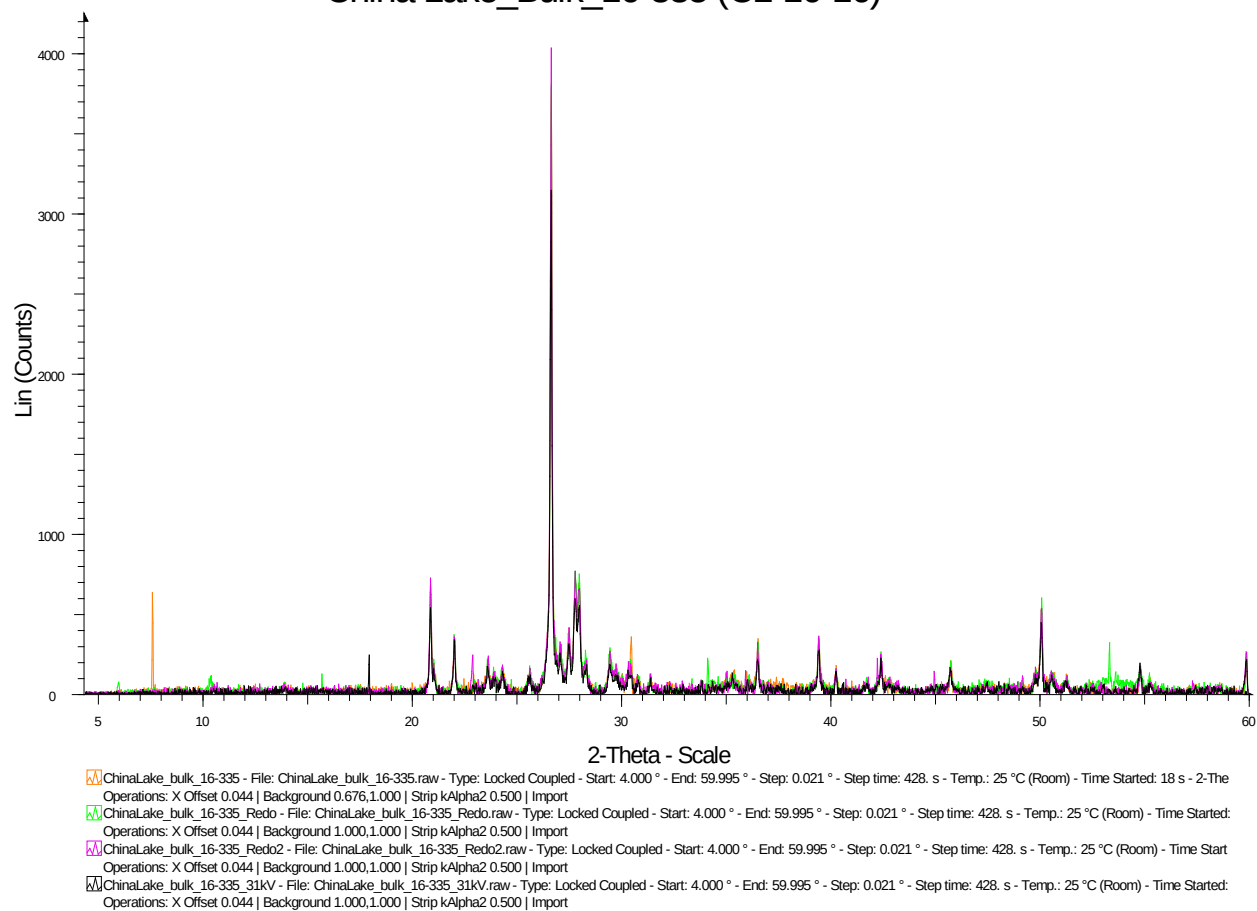
China Lake_Bulk_16-334 (CL-16-15)



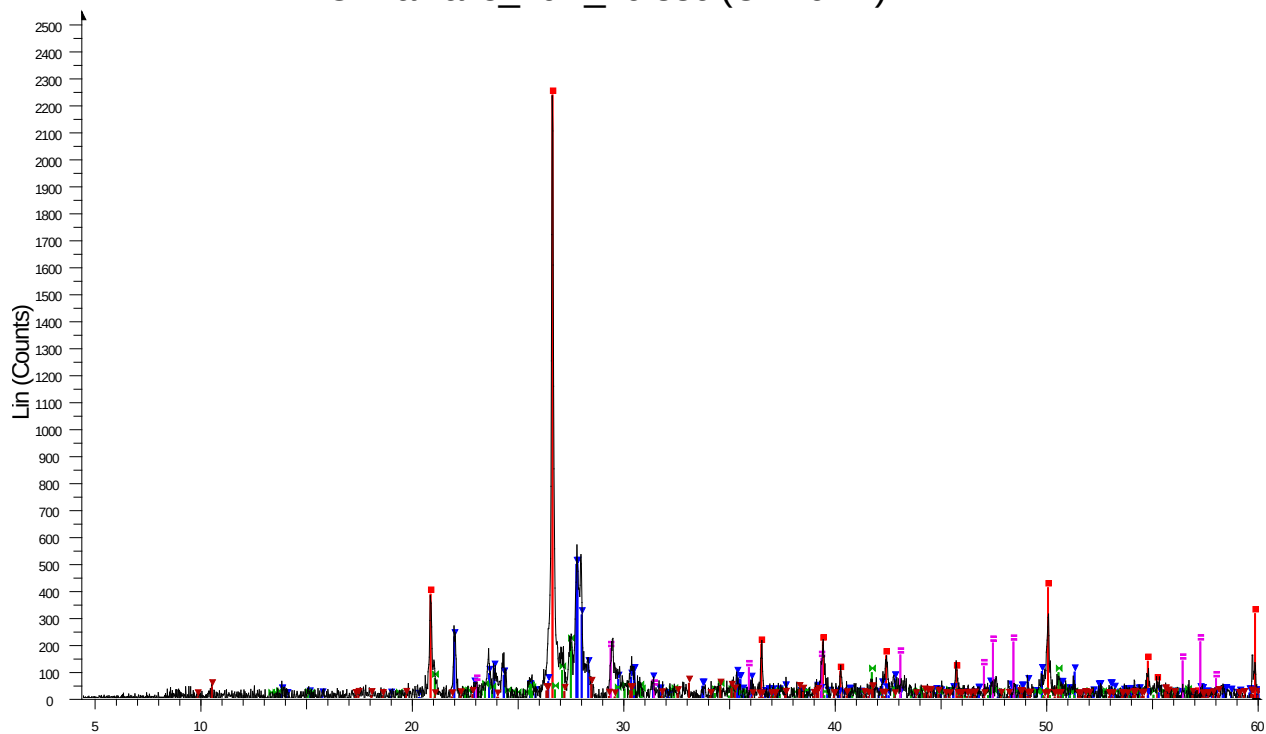
China Lake_Bulk_16-335 (CL-16-16)



China Lake_Bulk_16-335 (CL-16-16)



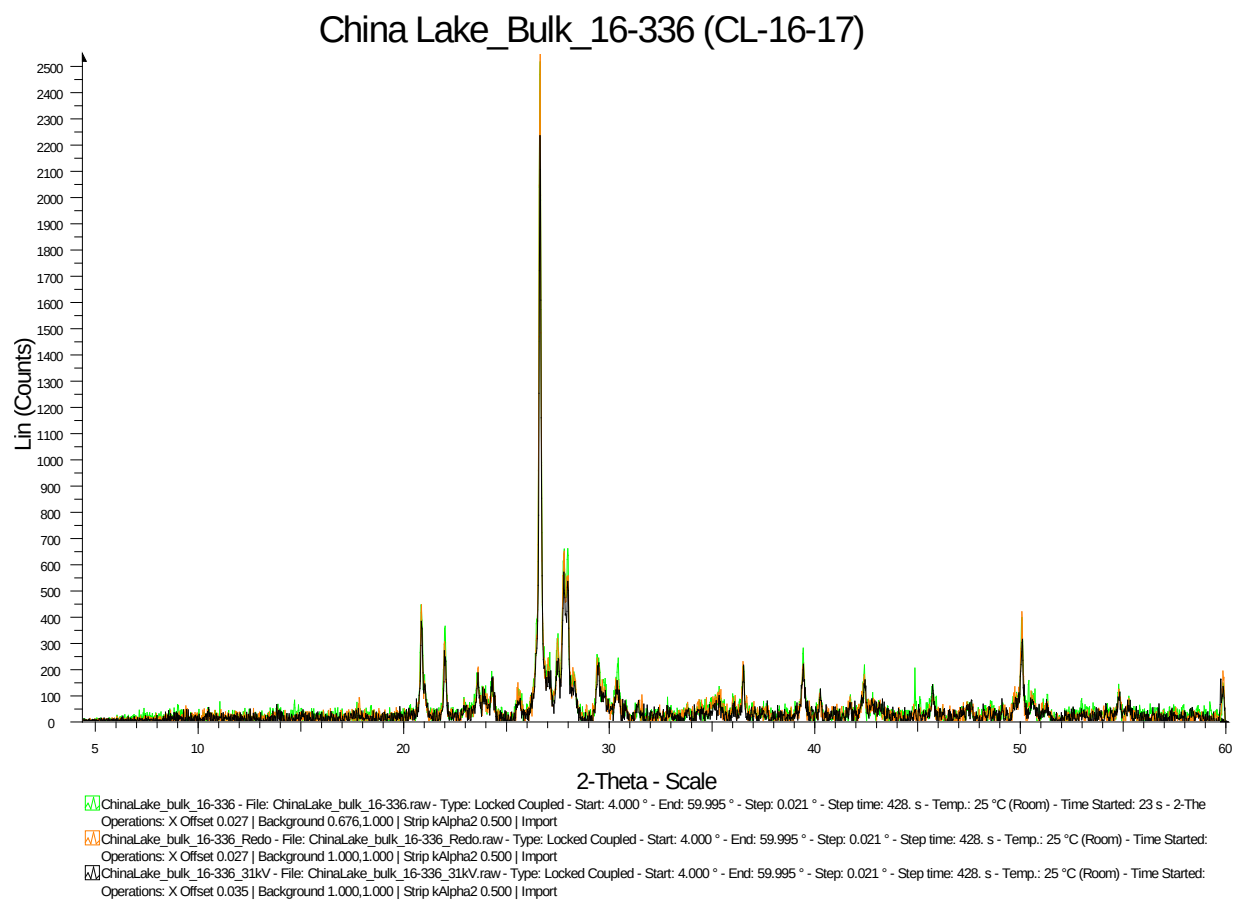
China Lake_Bulk_16-336 (CL-16-17)



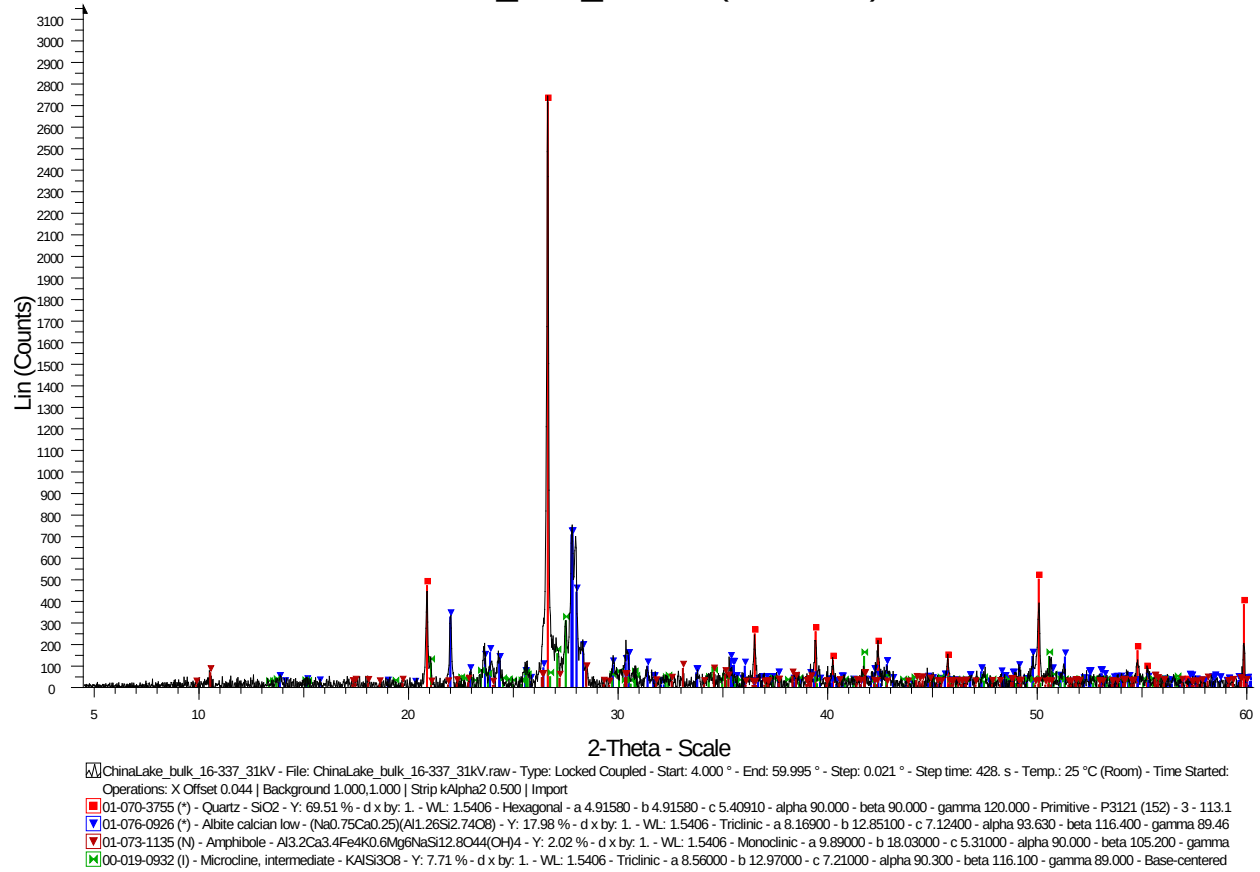
2-Theta - Scale

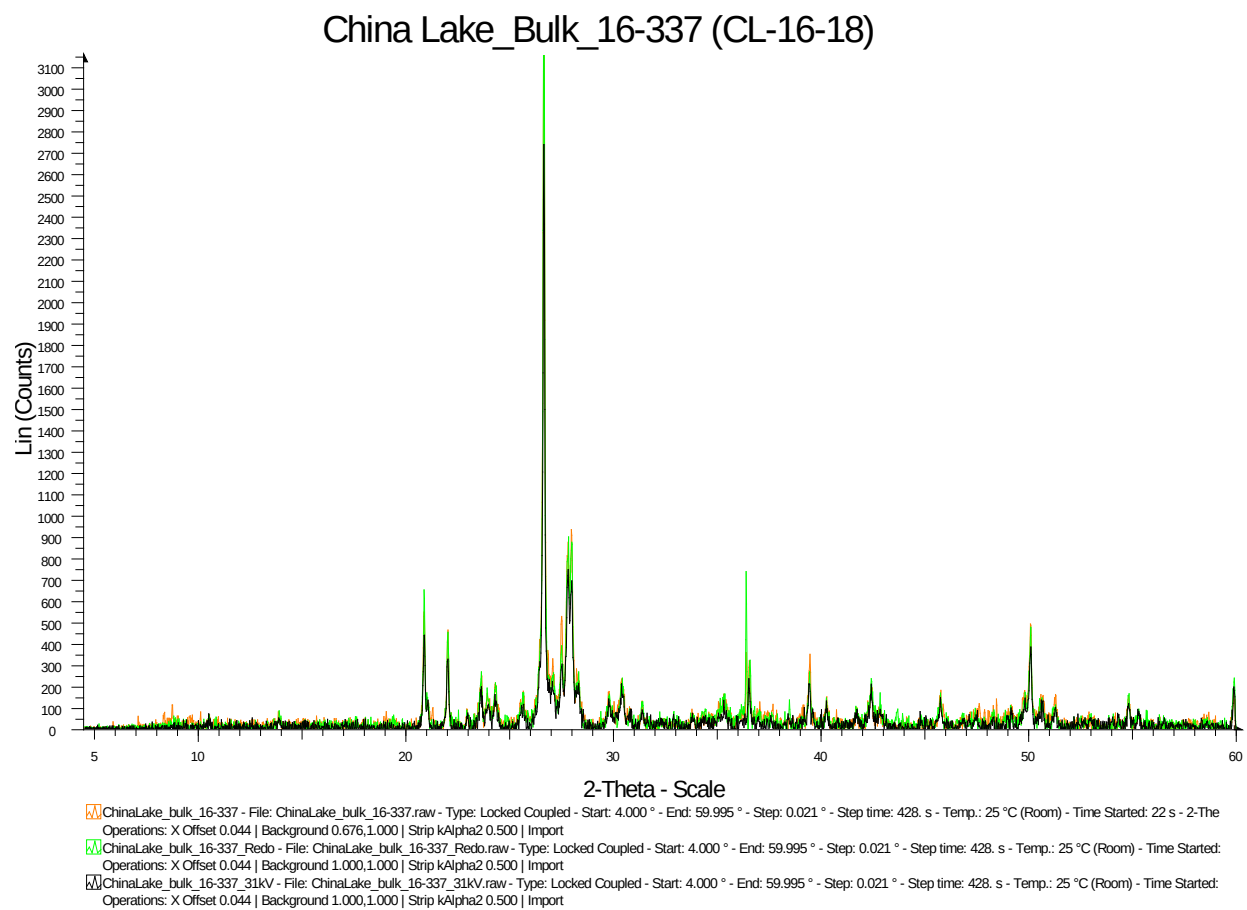
ChinaLake_bulk_16-336_31kV - File: ChinaLake_bulk_16-336_31kV.raw - Type: Locked Coupled - Start: 4.000 ° - End: 59.995 ° - Step: 0.021 ° - Step time: 428. s - Temp.: 25 °C (Room) - Time Started:
 Operations: X Offset 0.035 | Background 1.000,1.000 | Strip kAlpha2 0.500 | Import

■ 01-070-3755 (*) - Quartz - SiO₂ - Y: 81.36 % - d x by: 1. - WL: 1.5406 - Hexagonal - a 4.91580 - b 4.91580 - c 5.40910 - alpha 90.000 - beta 90.000 - gamma 120.000 - Primitive - P3121 (152) - 3 - 113.1
▼ 01-076-0926 (*) - Albite calcian low - (Na_{0.75}Ca_{0.25})(Al_{1.26}Si_{2.74}O₈) - Y: 18.01 % - d x by: 1. - WL: 1.5406 - Triclinic - a 8.16900 - b 12.85100 - c 7.12400 - alpha 93.630 - beta 116.400 - gamma 89.46
▼ 01-073-1135 (N) - Amphibole - Al_{3.2}Ca_{3.4}Fe₄K_{0.6}Mg₆NaSi_{12.8}O₄₄(OH)₄ - Y: 1.87 % - d x by: 1. - WL: 1.5406 - Monoclinic - a 9.89000 - b 18.03000 - c 5.31000 - alpha 90.000 - beta 105.200 - gamma
▼ 00-019-0932 (I) - Microcline, intermediate - KAlSi₃O₈ - Y: 7.42 % - d x by: 1. - WL: 1.5406 - Triclinic - a 8.56000 - b 12.97000 - c 7.21000 - alpha 90.300 - beta 116.100 - gamma 89.000 - Base-centered
■ 00-004-0636 (D) - Calcite - CaCO₃ - Y: 13.87 % - d x by: 1. - WL: 1.5406 - Rhombo.H.axes - a 4.99500 - b 4.99500 - c 17.06000 - alpha 90.000 - beta 90.000 - gamma 120.000 - Primitive - R-3c (167) -

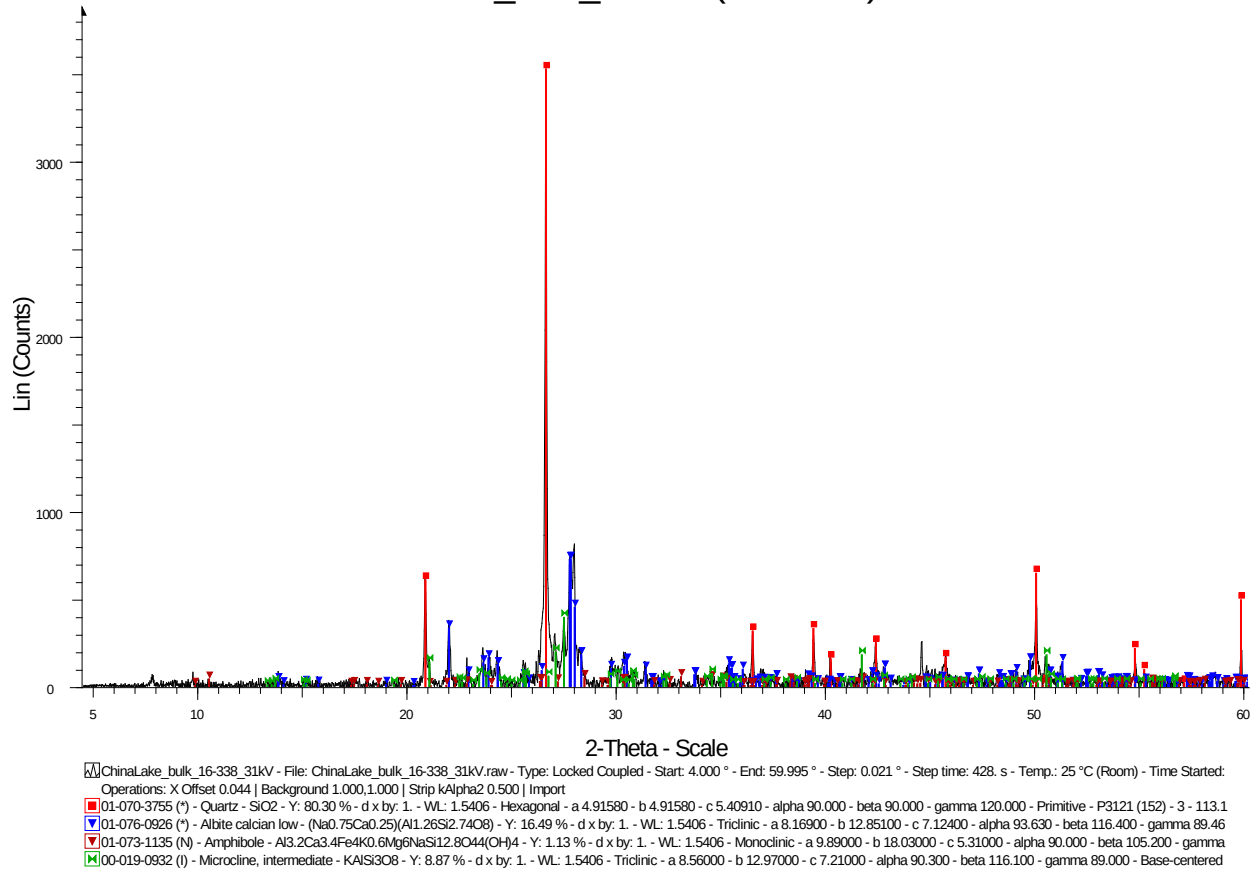


China Lake_Bulk_16-337 (CL-16-18)

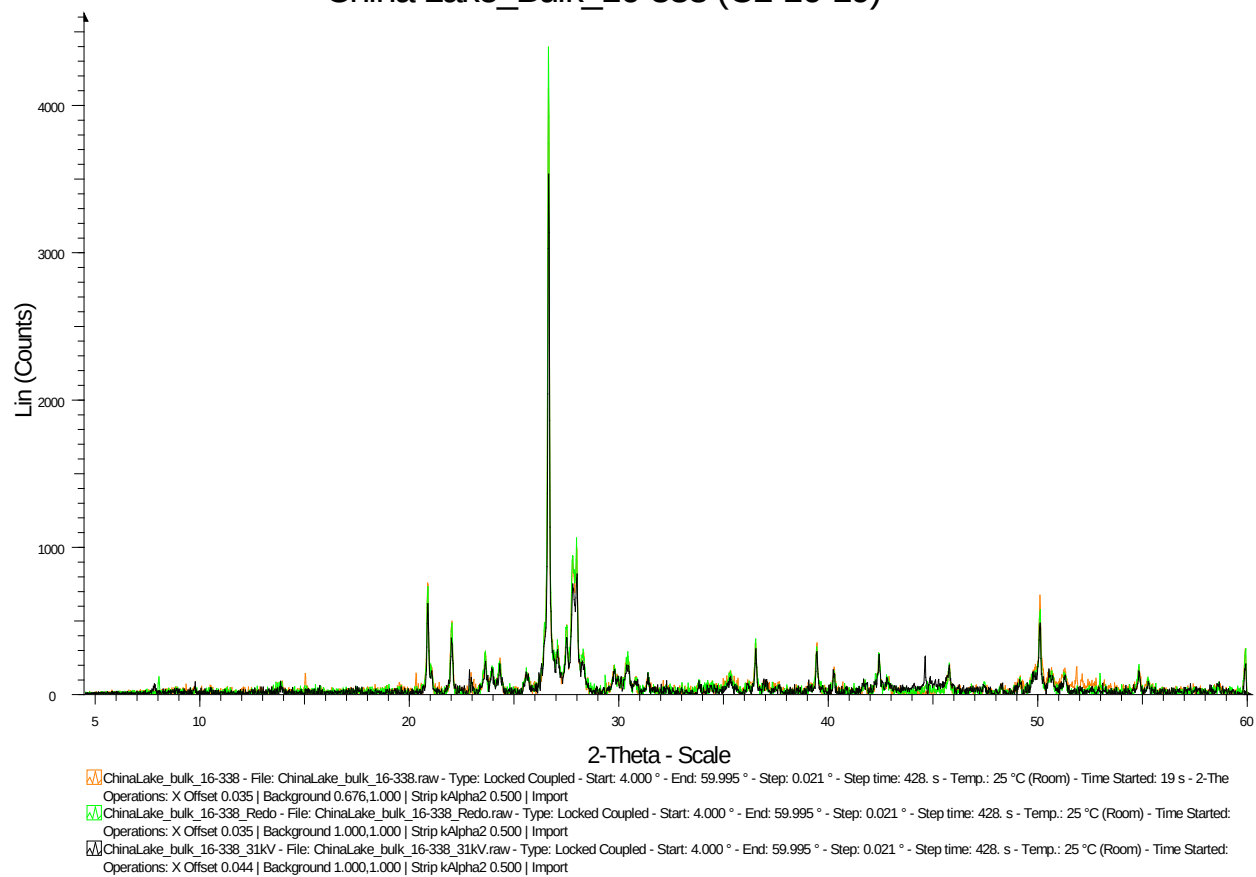




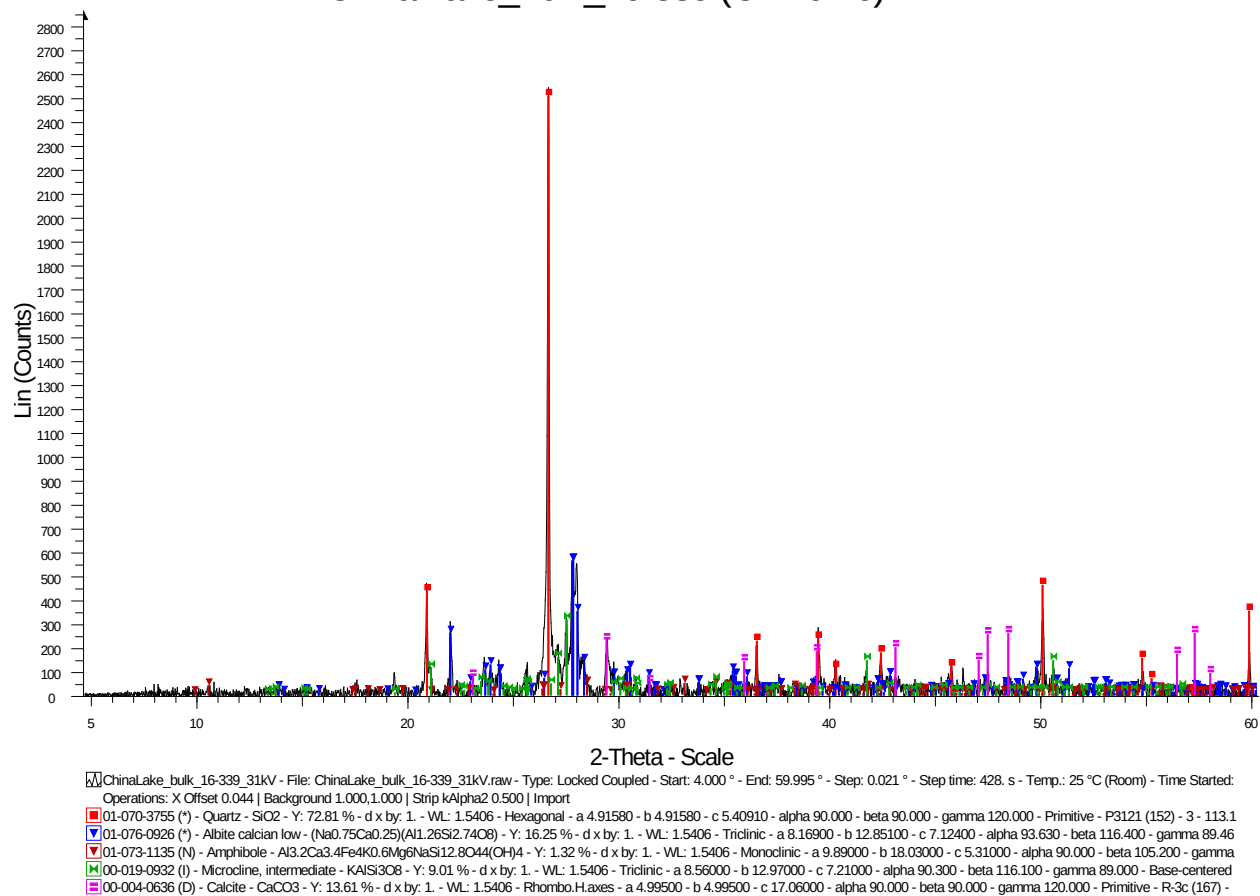
China Lake_Bulk_16-338 (CL-16-19)



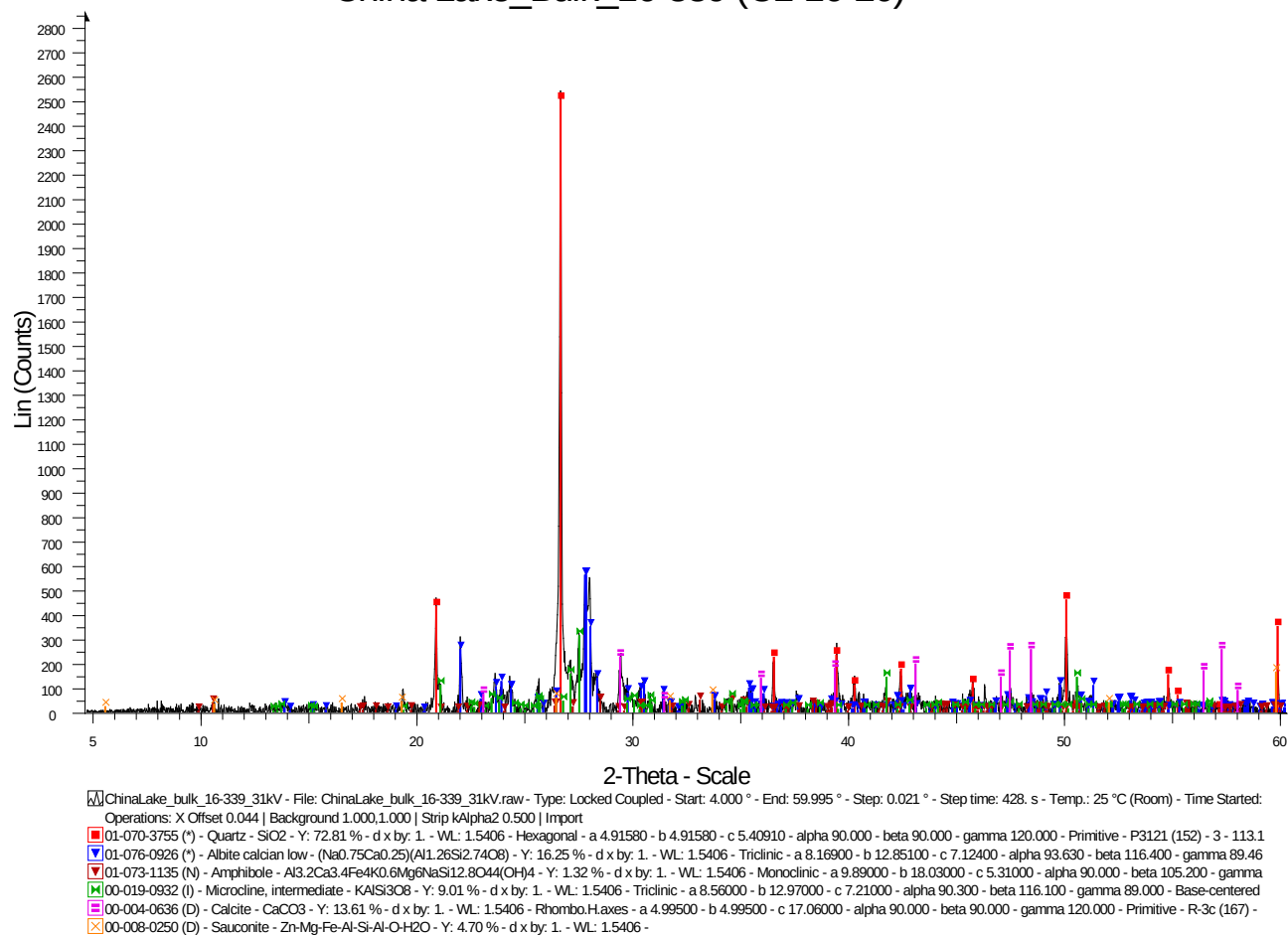
China Lake_Bulk_16-338 (CL-16-19)



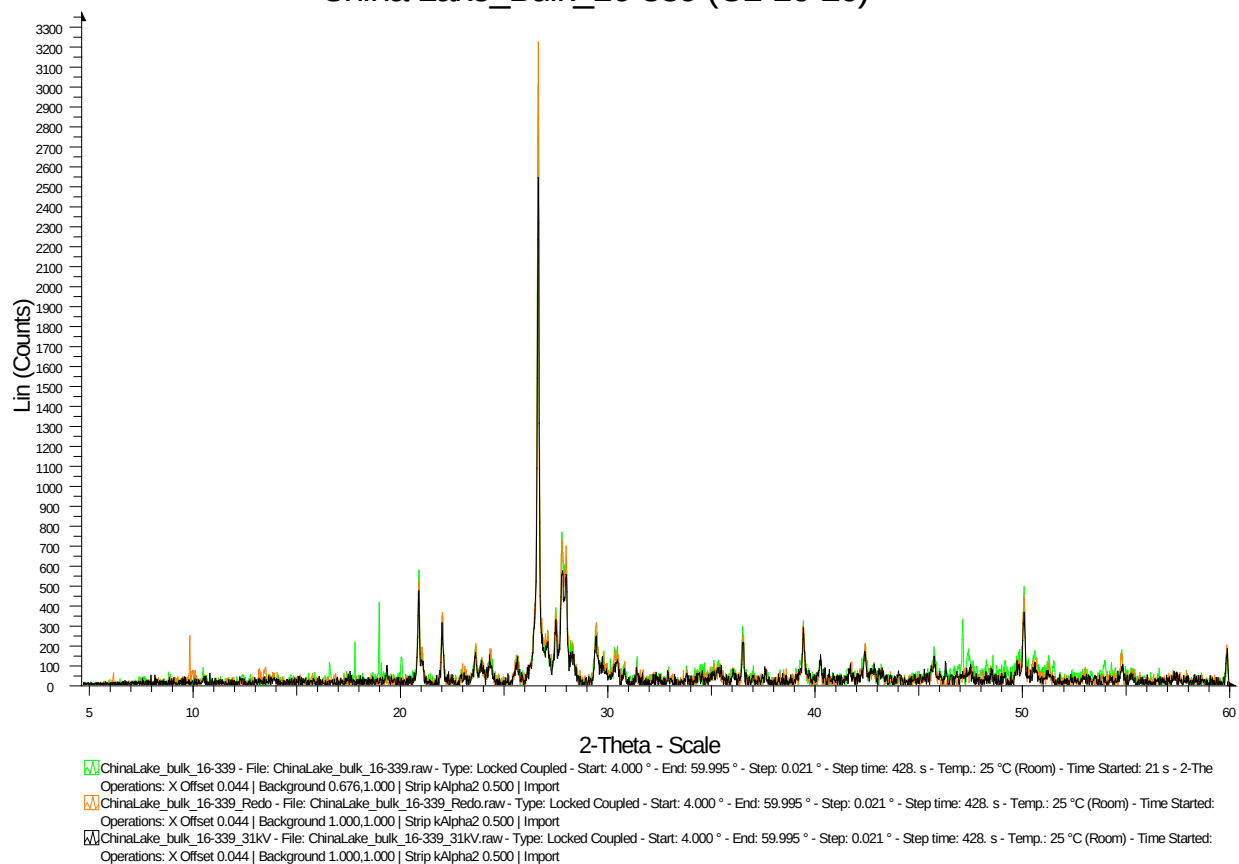
China Lake_Bulk_16-339 (CL-16-20)



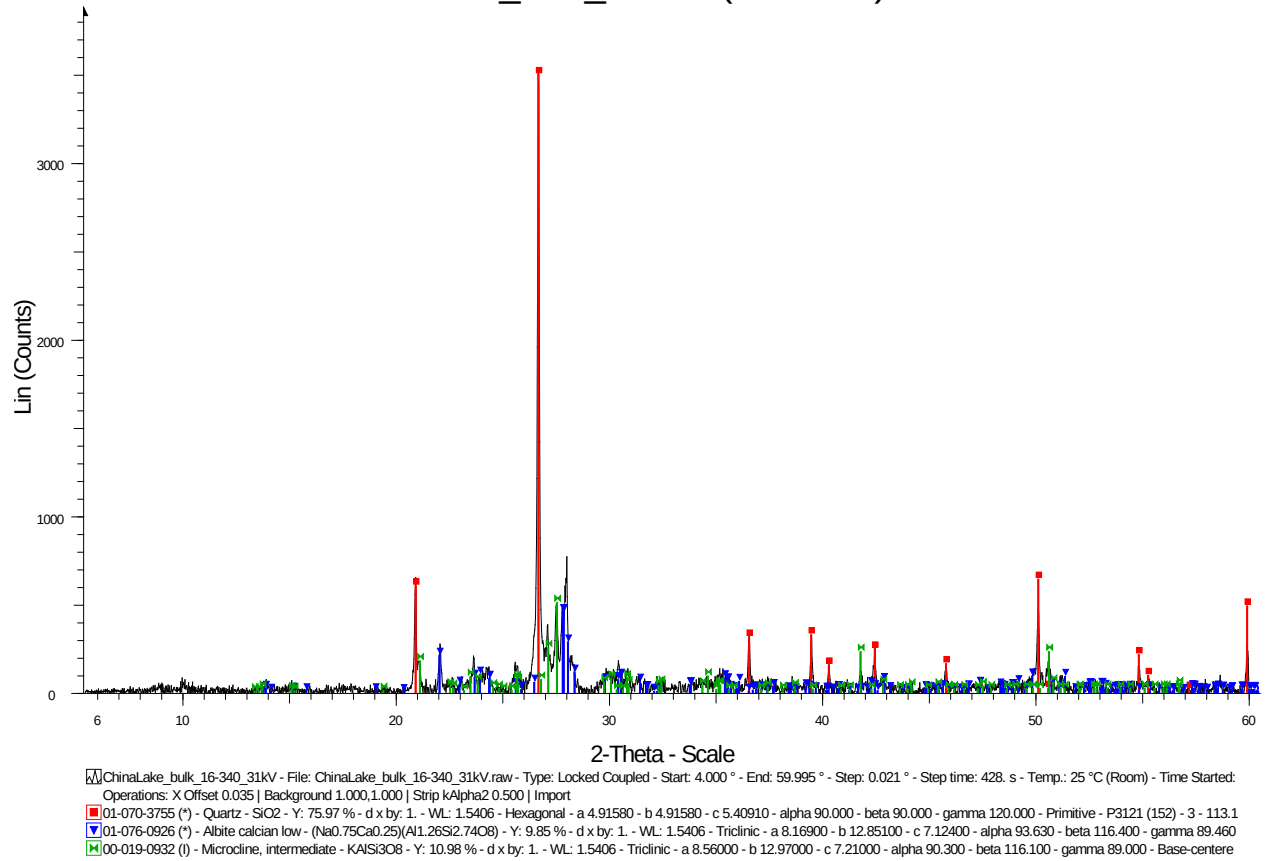
China Lake_Bulk_16-339 (CL-16-20)



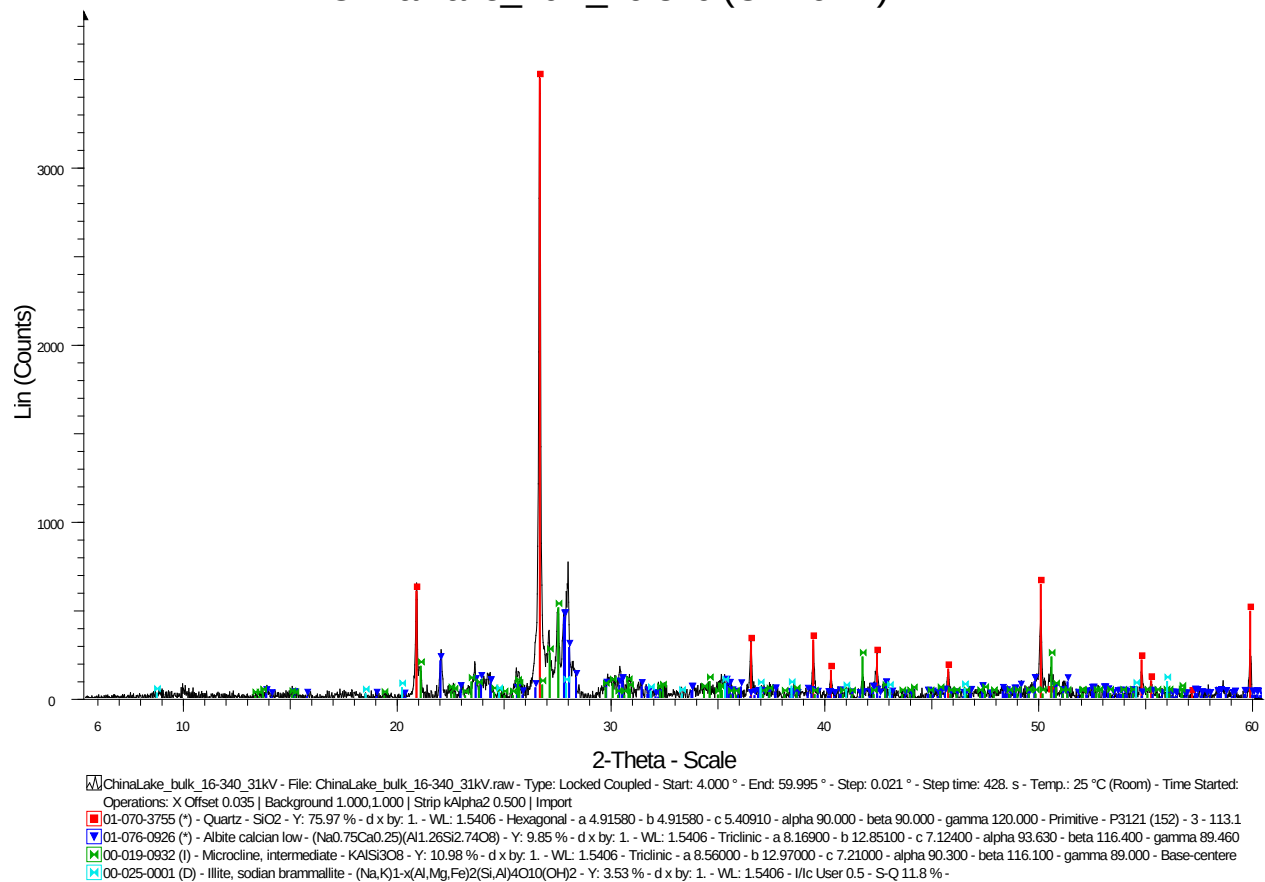
China Lake_Bulk_16-339 (CL-16-20)



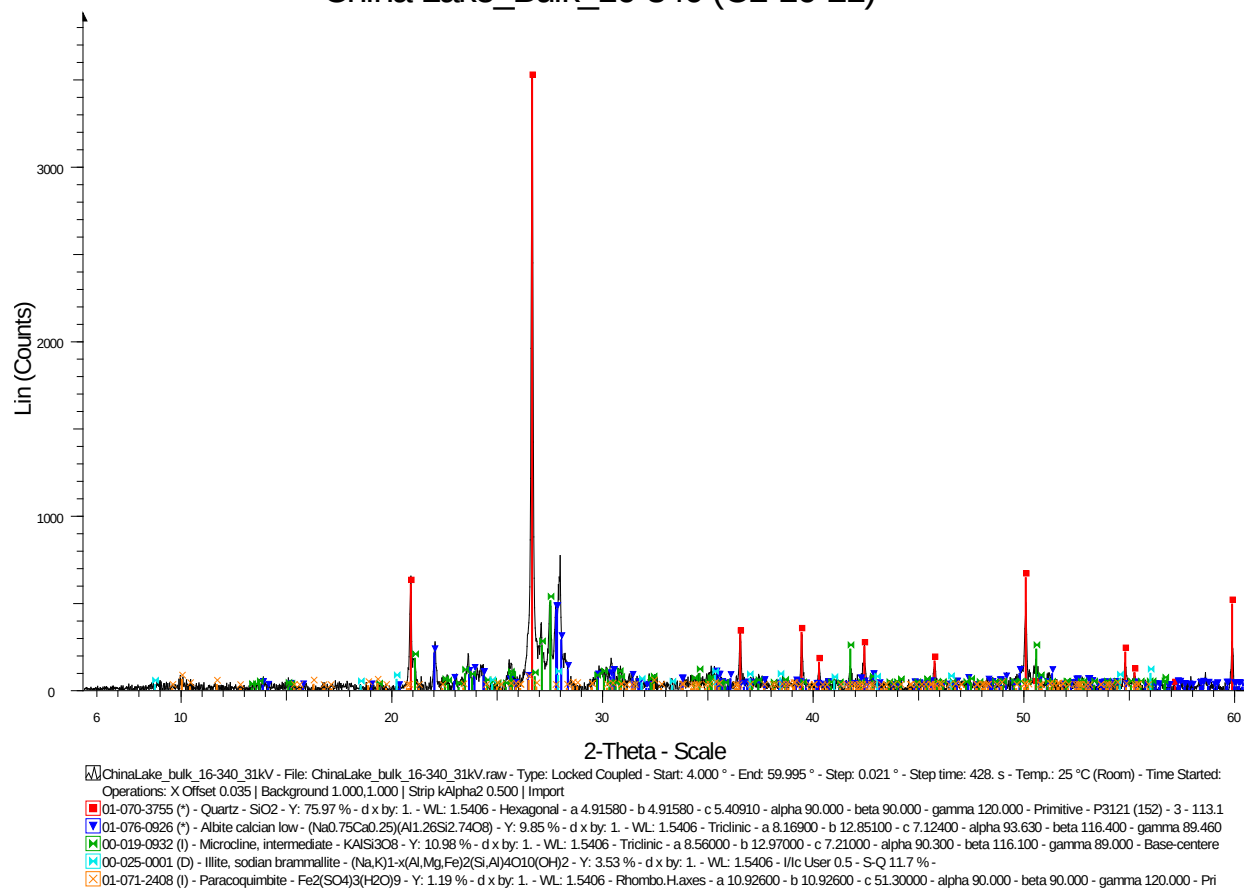
China Lake_Bulk_16-340 (CL-16-21)

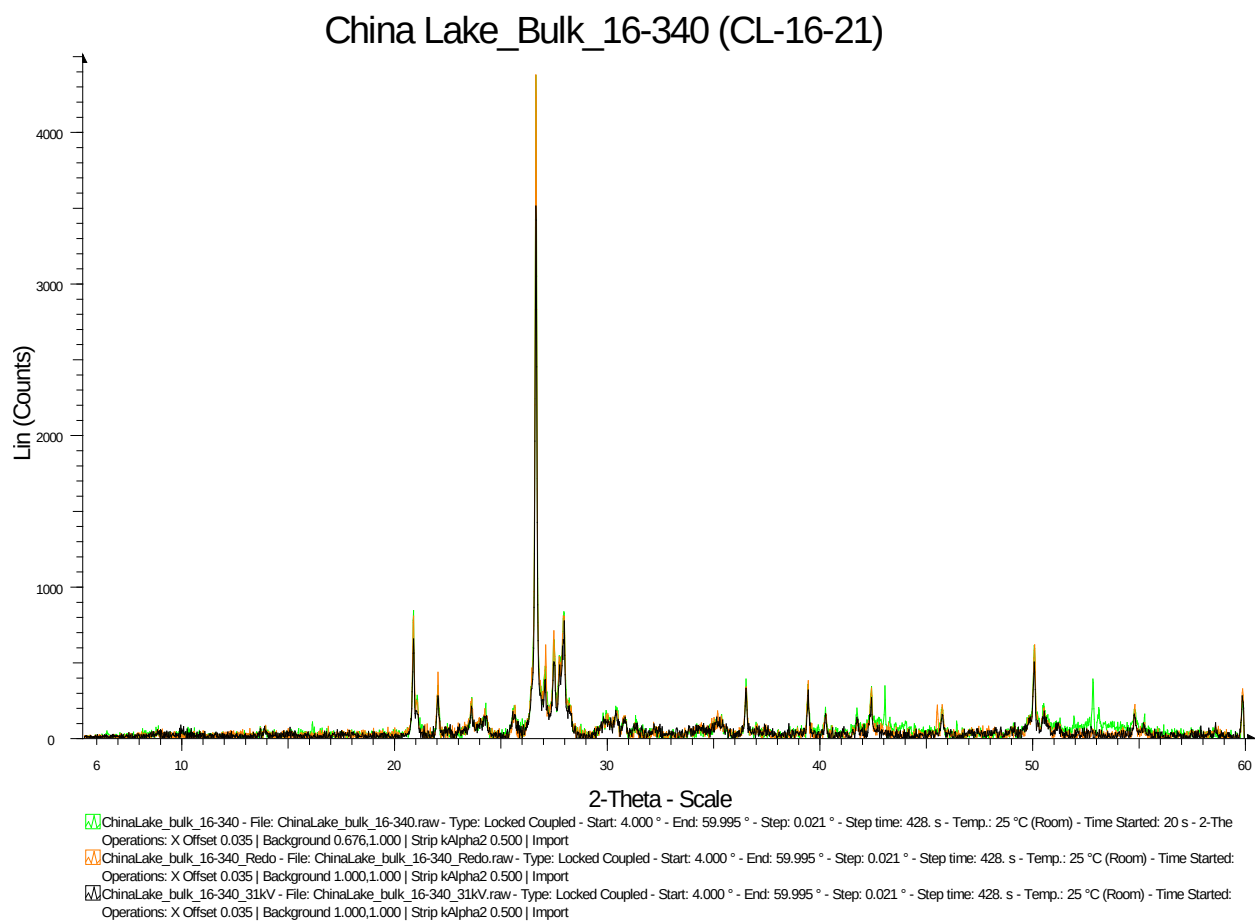


China Lake_Bulk_16-340 (CL-16-21)



China Lake_Bulk_16-340 (CL-16-21)





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