REMEDIAL WORKS AND HAZARD
MANAGEMENT OF URBANIZED LAND AT
THE OLD GUNNISLAKE MINE

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Urbanisation of the former Old Gunnislake Mine Snett in Cornwall has largely taken place during the past two decades. On June 20 1992, a major ground collapse occurred at the site of the main engine shaft, threatening the stability of King Street and adjacent property. Investigations were initiated to identify the cause of the collapse and safety of all Council owned land within the Old Gunnislake Mine Snett. A second capped unstable shaft (Russells) was located under a common access footpath central to a group of old peoples dwellings.

Mine drainage is to the River Tamar. The single deep adit is blocked and a shallow inadequate adit system is deteriorating. Investigations indicate that a 10m rise in ground water can occur over a 3 day period in response to a 1 in 5 year storm.

Subsidence at the previously capped Michaels Shaft was the result of a collapsing scour feature at the base of the 25m of mine waste above bedrock collapsing when ground water levels were at their lowest. The ground was secured and reinstated by forming a grout cap to the shaft above bedrock. High level adit drainage was maintained during grouting and a shaft sank from which radial and vertical drainage has been installed to maintain ground water status quo.

At Russells Shaft a plug was formed by compaction grouting in the shaft below rock head. High level adit drainage was preserved by forming a grout curtain between a collapsed section of adit and loose material within the zone of potential ground collapse over the shaft. Loose ground was subsequently grouted using permeation and compaction grouting techniques.

Over the past 40 years there has been an increasing incidence of mine related subsidence and damage causing water issues within the former Snett of Old Gunnislake Mine.

Relief wells to improve mine drainage are proposed as the major part of a hazard management strategy.

INTRODUCTION

The old rural settlement of Gunnislake is located in South East Cornwall on the steeply sloping valley of the River Tamar within the administrative authority of Caradon District Council. Geologically, it is founded on a small granite cupola between the two larger granite masses of Bodmin and Dartmoor. The granite was emplaced into Devonian rocks during the late Carboniferous and early Permian. Metalliferous mineralisation associated with granite emplacement occurred along E-W trending fractures and formed important copper and tin lodes. Wolfram was also present. Cross courses trending NNW-SSE post-date east-west lode structures and displaced them. Metalliferous mineralisation has taken place in these cross courses associated with lower temperatures than east-west lode mineralisation, it was less extensive and principally involved lead and silver. A simplified geological plan is shown in fig 1.

Gunnislake has been an important mining centre for many hundreds of years. The steep valley sides rising over 175m above the river has allowed extensive development of mines drained by adits driven into the hillside just above river level. Mining was carried out from levels driven along the lodes. Where the lode was of economic quality, ore was extracted between levels. Levels were joined by cross cuts driven along cross courses. Workings along cross courses were occasionally developed.

The steep sided valleys also allowed surface streams to be conducted to provide water power to the mines. Even after steam power was provided in the early to mid-nineteenth century, water was still used as the major source of motive power.

Old Gunnislake Mine was one of several mines that worked a series of east-west trending lodes. Of these mines, Old Gunnislake Mine was the oldest and has probably been worked from at least as early as the sixteenth century, when the first ore returns were recorded. Working was not continuous but was linked with variation in ore price and improvements in technology. The mine was finally abandoned in 1872.
COLLAPSE

On 20 June 1992, sudden subsidence left a vertically sided crown hole in the rear garden of a privately owned 3-bedroomed house in Woodland Way, Gunnislake (plate 1). The estate had been built in 1972. The suddenness and size of the subsidence feature, which measured some 9m diameter by 7 to 8m deep, caused alarm amongst the local population and received much media attention. The collapse disrupted electricity and gas services, severing an 11kv electricity power supply. Two electricity poles were lost in the collapse. The end of one pole was just visible above the top of the collapse.

Rainfall in the 2 months prior to the collapse had been low - less than 35mm for the whole 2 month period. The rainfall hydrograph for the period around the collapse is shown on fig 2.

INVESTIGATION

Soon after the collapse occurred, John Grimes Partnership was engaged by Caradon District Council.
Desktop studies proved that the collapse had occurred at the site of the original engine shaft (known as Michaels Shaft) to the Old Gunnislake Mine. Records for the original council development indicated that the shaft had been capped with reinforced concrete as part of enabling works prior to the construction of the dwellings. No cap construction details survive.

Borehole investigations showed the collapse to have occurred in superficial material between 20 and 30m thick. Loose collapsed material was proved to extend vertically below the crownhole to bedrock. A boulder layer, local to the collapse feature was identified just above bedrock.

Preliminary studies indicated the presence of three other recorded shafts (Russells, Gribbles and Cockings) associated with the Old Gunnislake Mine to be within or close to council property.

Several conflicting shaft location records existed. Aerial photographs from 1946 and 1988 were studied in stereopairs. Desk top studies were augmented by geophysics. Geophysical investigations included offset Wenner resistivity traversing and profiling and magnetic traversing. Ground Probing Radar was used in areas where soil resistivity results indicated penetration depths greater than 10m would be achieved.

Boreholes were drilled at locations where desk top studies or geophysics indicated the possible presence of a shaft on Local Authority owned land or immediately adjacent.

Boreholes proved:

1. The locations of Cockings and Russells Shafts and the verification of associated ground conditions. Gribbles Shaft was not located. Desk top studies indicate that its most likely position is remote from public space or Local Authority owned land.

2. A system of shallow drainage adits driven along lodes and cross courses.

3. The presence of between 10 and 25m mine waste extending across an east-west tract of land 500m wide in the vicinity of Michaels Shaft.

Collation of recorded collapses are tabulated (table 1). These all occur to the east of Michaels Shaft where a system of shallow adits, typically with rock cover not more than 2m was found. Investigation proved this adit system was hydraulically inefficient. Evidence of roof collapse and blockage was found.

A mining composite was prepared from investigation results and is reproduced in figs 3a and b.

**GROUNDWATER**

Old Gunnislake Mine workings were originally drained by a deep adit system with a single outfall or portal. The depth to the deep adit is some 70m at Michaels Shaft. Since the closing of the mine in 1872, the deep adit has become increasingly blocked so that issuing flow, even during times of extreme wet weather, is now no more than a trickle.

A number of standpipes installed during the investigation have been monitored since September 1992. Positions of key standpipes are shown on fig 4. Fig 5 shows groundwater and rainfall hydrographs from September 1992 to April 1994.

Monitoring has confirmed that:

1. Soil groundwater may respond rapidly in the vicinity of the shallow adit system by over 3m/day with a lag time between rainstorm event and soil water rise of the order of 3 days. Furthermore, groundwater may fluctuate on an annual basis by as much as 14m.

2. A shallow adit system, although much collapsed and infilled, has a significantly higher permeability than the adjacent rock mass or mine waste over. The adit concentrates surface water falling over a large catchment area through a system of largely uncollapsed upstream sections towards a more restricted single adit, at and to the east of, Cockings Shaft. Perforations in the shallow adit roof allow soil to be significantly recharged over the collapsed zone. Losses in head along the shallow adit measured between Russells and Cockings Shafts were of the order of 1m per 10m.
KEY

□ ADIT PORTAL KNOWN POSITION.

■ EXACT POSITION NOT KNOWN.

● SHAFT POSITIONS AT SURFACE, KNOWN POSITION.

○ EXACT POSITION NOT CERTAIN/OR INFERRED.

RS RUSELLS SHAFT.

CS COCKINGS SHAFT.

MS MICHAELS SHAFT.

WS WILLIAMS SHAFT.

LODE AREA BETWEEN SURFACE LODE OUTCROP AND DEEP ADIT LEVELS. (Tick on down dip side.)

LODE ALONG DEEP ADIT LEVEL (CONJECTURED).

LODE AREA BETWEEN DEEP ADIT LEVEL AND DEEPEST KNOWN LEVELS.

☐ COUNCIL ESTATES.

--- GREAT CROSS COURSE.

Fig 3a Summary of Mining Features
Fig 3b  Summary of Hydrology Related Mining Features
Prior to 1992, collapses over the shallow adit system were to the east of Cockings Shaft. Subsequent collapses have been to the west of this shaft. Fines lost into the adit system are trapped behind blockages reducing the permeability of the eastward downstream adit section, reducing overall drainage capacity and increasing soil recharge. It would appear that groundwater recharge of mine waste west of Cockings Shaft is an increasing phenomenon, with groundwater rising close to ground level in two consecutive years.

The soil groundwater response in the vicinity of subsiding ground at Nos 7 and 8 Woodland Way (Table 1) is made more complex by the additional contribution of water supplied by a disused leat system some 10m below present ground level. Maximum groundwater rise occurs within 2 days of any rainfall event and is locally elevated around the zone of subsidence.

Analyses of groundwater sampled from various depths have indicated circulatory movement of groundwater in the workings.

**SHAFT COLLAPSE RISK**

The most probable collapse mechanism for Michaels Shaft was propagation to surface of a large void sited over the shaft in the mine waste above rock head at a time when ground water levels were at their lowest. A failure of the shaft collar was followed, over a period of time, by scour of material into the shaft during groundwater drawdown. Scour was facilitated by high groundwater fluctuations and the presence of local highly permeable boulder layer at the base of mine waste.

At Russells Shaft despite similar high groundwater variation and mine waste depths in excess of 25m, no comparable voided ground was proved. There was direct connection between mine waste and shallow adit system. Weak timber staging supporting mine waste over the bedrock shaft was identified. The mine waste around the shaft above bedrock was also found to be very loose. A high collapse risk was assigned and recommendations to securely cap the shaft made.
The third shaft to be identified was Cockings Shaft. This shaft was capped (on abandonment) with massive granite sets located within original superficial material. Mine waste subsequently covered them. The cap dimensions were significantly greater than the bedrock shaft dimensions. Groundwater did not fall below the level of the cap. It was recommended to Caradon District Council that collapse risk compared to Russells Shaft was low. Other situations are likely to exist where collapse risk is greater.

**REMEDIAL WORKS IN THE OLD GUNNISLAKE MINE SETT**

Due to the high and fluctuating water table and deep superficial cover, it was not economically viable to physically excavate to bedrock level to cap either Michaels or Russells shafts. A compaction grouted cap and permeation grouting of superficial material above proved the most economic solution for both shafts. The requirement to preserve shallow adit drainage in both cases was paramount. In Michaels Shaft, shallow adit was intact, in Russells Shaft it had collapsed. Treatment at rockhead was different in both cases (figs 6 and 7).

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**Fig 5**

Rainfall/Standpipe Hydrographs (for locations see fig 4)

Michaels Shaft

The collapse was stabilised by a reinforced sprayed concrete collar designed so that a steel platform could be constructed over the top of the collapse to allow a 10 tonne drilling rig to work over the shaft. Investigations proved the presence of adit drainage some 2-3m below rockhead level. It was therefore necessary to place the grout cap in such a way to ensure that grouting of the adit did not occur. Tube à Manchette grouting on a triangular pattern with 1.5m side length was adopted by grouting contractor Soletanche. UPVC pipes were installed along the length of the Tube à Manchette to the depth of the cap to allow sodium silicate injection during cap grouting. Prior to grout installation, vibrating wire piezometers were installed into the shallow adit drainage both upstream and downstream of the shaft to monitor changes in head during grouting operations. A conductivity cell was placed in the lower piezometer hole to measure changes in conductivity which might result from grout water mixing.
Fig 6 Remedial Works to Michaels shaft

Fig 7 Remedial Works to Russells Shaft
Table 1  Chronology of Known Occurrences in Gunnislake (from 1960's to present day)

<table>
<thead>
<tr>
<th>Date</th>
<th>Type</th>
<th>Location</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950's</td>
<td>Crown Hole</td>
<td>No 7 Commercial Road</td>
<td>Ground collapse</td>
</tr>
<tr>
<td>1950-1950</td>
<td>Shaft Collapse</td>
<td>No 1 Commercial Road</td>
<td>Ground collapse on 2 occasions at location of Quillets Shaft</td>
</tr>
<tr>
<td>1950-1969</td>
<td>Crown Hole</td>
<td>Junction of King Street and Orchard Road</td>
<td>Collapse on 4 occasions over span of 40 years</td>
</tr>
<tr>
<td>Late 1960's</td>
<td>Crown Hole associated with collapse over shallow adit</td>
<td>House opposite Strasbourg Terrace</td>
<td>1 x 5 x 1.5 x 2.5m deep collapse. Ochreous water issues</td>
</tr>
<tr>
<td></td>
<td>Crown Hole associated with collapse over shallow adit</td>
<td>House opposite Health Centre</td>
<td>Large collapse in road, heavy water issues. Possibly on water issues. Possibly on more than one occasion</td>
</tr>
<tr>
<td>Seasonal</td>
<td>Elevated groundwater associated with shallow adit drainage</td>
<td>No 4 New Cottages</td>
<td>Heavy seasonal ochreous seepage in garden</td>
</tr>
<tr>
<td>1980</td>
<td></td>
<td>Health Centre</td>
<td>Well cracked and dropped</td>
</tr>
<tr>
<td>1990's</td>
<td></td>
<td>Health Centre</td>
<td>Depression in adjacent property</td>
</tr>
<tr>
<td>1990's</td>
<td>Subsidence Feature</td>
<td>Russells Close</td>
<td>Depression in paved area</td>
</tr>
<tr>
<td>December 1991</td>
<td>Crown Hole</td>
<td>Junction of King Street and The Orchard</td>
<td>Collapse of ground adjacent to original pressure relief well constructed C 1950</td>
</tr>
<tr>
<td>June 1992</td>
<td>Shaft collapse</td>
<td>No 1-2 Woodland Way</td>
<td>Major collapse over main engine shaft to Old Gunnislake Mine</td>
</tr>
<tr>
<td>August 1992</td>
<td>Shaft</td>
<td>Tregonning</td>
<td>Collapse of timber capping over Williams Shaft. Hole opened up 2.5m diameter 30 deep</td>
</tr>
<tr>
<td>November 1992</td>
<td>Elevated groundwater associated with shallow adit drainage</td>
<td>Rose Cottage and No 2 King Street</td>
<td>Major issues of groundwater resulting in structural damage to floor slab</td>
</tr>
<tr>
<td>November 1992/ December 1993</td>
<td>Subsidence Feature</td>
<td>No's 7 &amp; 8 Woodland Way</td>
<td>Settling depression in front garden and associated loosening of ground active during rapid drawdown</td>
</tr>
<tr>
<td>December 1993</td>
<td>Subsidence Feature</td>
<td>Rose Cottage</td>
<td>Depression forming in garden</td>
</tr>
</tbody>
</table>

Russells Shaft

Shallow adit was located close to the shaft, the roof of the adit in the vicinity of the shaft had collapsed. The cap had to be formed below the level of the shallow adit and permeation grouting carried out around the adit. To prevent grouting of the shallow adit, a grout curtain was first constructed to control the lateral migration of grout into the shallow adit. Both upstream and downstream of the shaft vibrating wire piezometers were again installed. Downstream, a conductivity meter was used to detect grout mixing. Inclinometer tubes were installed in the grout curtain to monitor movement during subsequent grouting.

FUTURE RISK MANAGEMENT

There is a need for risk management. Historical collapses and recent events have shown that ground instability is directly related to the inadequacy of a failing shallow adit system, and large and rapid groundwater fluctuation induced into the soil system by adit surcharge. Recent events (table 1) have indicated the need to control groundwater. Relief well drainage with the design criteria to attenuate events similar to that in 1992 by 5m is currently being designed.

Pressure Relief Well Scheme

A pressure relief scheme has been in place along the line of the shallow adit since the 1970s. The well, located at the junction of King Street and Orchard Road is connected to, and drained by, a surface water sewer which has an invert depth of approximately 4.0m at its intersection with the pressure relief well.

This present system is inadequate to regulate the present water level variations. It is proposed to upgrade the existing pressure relief well and provide further deep relief of water via an additional well just upslope of Cockings Shaft. These wells will be linked and groundwater discharged into the existing surface water sewer.
The upslope deep relief well is designed to intercept water flowing along the two shallow adits connecting Russells and Michaels Shafts with Cockings Shaft.

The advantages of this scheme with respect to operational risk are twofold. Firstly, the relief of the groundwater is continual and will commence as soon as groundwater levels rise above the level of gravity drainage. Secondly, as a gravity system, there is no risk of power failure during heavy rainfall negating the effectiveness of the scheme.

The new system should lower water levels to 5m below critical groundwater levels.

Present Situation and Management of Risk

Mine drainage has always concentrated groundwater towards points of discharge (adit portals). When in operation, deep adit would have provided most of the drainage from the mine. On abandonment it would have been deliberately blocked significantly reducing drainage along this conduit. Later collapses along deep adit would have further reduced the effectiveness of this drainage path. Currently drainage from deep adit is negligible.

Shallow adit discharges via a drainage conduit beneath the main Gunnislake - Tavistock road and it is probable that at the time of abandonment, shallow adit drainage was maintained. Subsequently, collapse along the shallow adit system has reduced the effectiveness of this drainage path.

Monitoring of groundwater levels from deep adit level indicate little vertical reduction in head between shallow and deep adit levels. Pressures of over 70m occur behind blockages along the deep adit system. During and following times of heavy rain, this hydrostatic pressure can be observed in the form of small jets of water issuing from joints in the rock mass adjacent to deep adit portal (plate 2).

A large area of Old Gunnislake Mine has now been urbanised. Present and future risks associated with the Old Gunnislake Mine must be managed in such a way that further collapses do not occur. Studies indicate there to be a number of risk scenarios existing within the Old Gunnislake area. These failures are directly related to the occurrence of extreme conditions.

1. Ground subsidence associated with shallow adit surcharge. Ground collapse mechanism may be catastrophic. Low probability of fatalities should collapse occur. Large areal extent over which collapse could occur. High risk to property.

2. Shaft collapse. Local but catastrophic collapse mechanism. High probability of small number of fatalities should collapse occur. Number of possible collapses low.

Plate 2. Seepage from rock adjacent to deep adit portal


Shaft remedial measures to date, the provision of a pressure relief scheme in the near future and ongoing strategic monitoring offer the most effective means of management.

It has been shown that risks to the urban areas located over the Old Gunnislake Mine from past mining activity exist due to a combination of factors. It is perceived that only a combination of remedial schemes whereby each element reduces or removes risk of collapse by one mechanism but is not detrimental and can be advantageous in reducing risk from other collapse mechanisms offers the only solution to the problems associated with the mine.

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