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3

Ground Control for Underground Evaporite Mine in Turkey

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1. Introduction

Ground control is the methodology applied to maintain all the risks associated with various forms of ground movement and inundation in underground mines within an acceptable level. It is applied to all stages of a mine – from feasibility through operation and finally abandonment.

Ground control methodology is largely determined as a function of the interaction of various qualities of the rock mass with various aspects of the mine planning and design methodologies. Depending on the nature of these interactions, rock support and reinforcement will required to achieve effective ground control.

Consequently, effective ground control may be considered to be a function of three main components:

- Site ground characteristics,
- Mine planning and design; and
- Ground support and reinforcement

Controlling the potential for hazardous ground movements and inundation of an underground mine to within acceptable limits is essential. Both hazards can result in serious harm or death of workers or persons that may inadvertently enter a mining area. The hazards are not always obvious. For example, the outcome of the hazard of a loose rock falling from a sidewall and striking someone can be fatal by either direct physical contact, or damaging the plant in which the worker is working. The presence of certain geological structure (natural planes of weakness in the rock) that override the effectiveness of any ground control measure, is not always obvious from within the mine.

In the case study given in this chapter, in situ and laboratory studies have been made to define the formations through which the drift has been driven. In situ engineering geology measurements were carried out consisting of field observation, mapping, boreholes and laboratory tests on samples collected from the trona field and the boreholes. After drift

excavation and support installation, the deformations and the loads on the supports were measured. As a result of this study, the deformational characteristics of the trona ore beds and weak rocks and their effect on the main drift (T-2000) deformation have been determined. In this study, some parameters for understanding the deformational behavior of trona are investigated including in situ rock support loads, rock properties, and geology and excavation sequence.

2. Background for failure mechanism of underground evaporite mines

Geology is one of the most important parameters determining the overall deformational behavior of an underground opening. With careful investigation of the geological details, it is often possible to explain the unexpected deformational behavior of an excavation(Wang et all, 2000). Deformation of underground salt, trona and potash mines is generally time dependent, providing for gradual adjustment of strata to mining induced stresses. Time dependence can allow for higher extraction ratios provided eventual failure can be tolerated. However, this eventual failure can be violent if creep deformation can shift stress and potential energy to strong, brittle geologic units.

Generally, room and pillar methods, short-wall methods and solution mining methods have been applied as production methods for all evaporite mines in the world. The mine failure case studies reviewed here illustrate this process. Yield pillars and defects in bridging strata figure prominently in these cases. Yield pillars provide local and temporary support to the roof, temporarily delaying the cave; and allowing extraction ratios and overburden spans to increase beyond the long term capacity of overlying strata. Defects (faults, voids, thinning) of strong overburden strata reduce the critical span, sometimes to less than panel width. Analyses of many of these cases have focused on a cascading pillar failure mechanism, but recent work and this review point to failure of strong overburden strata as the essential element. The suddenness of failure and attendant seismic events pose hazards to miners and, in some cases, to those on the surface(Whyatt, J., 1998).

Trona is generally much stronger and stiffer than the immediate roof and floor rocks, with the degree of contrast varying with different beds and locations. Trona shows some time-dependent behavior, but few laboratory creep tests have been performed in this study. Much of the time-dependency exhibited in the field may in fact represent creep of weaker roof and the floor strata rather than the trona bed itself. Many researchers suggest that, if the deformations around underground excavations are carefully measured in situ, the field measurements provide a better understanding of the deformational behavior of underground excavations(Onargan et al, 2006).

3. Case study: Beypazari trona mine

3.1 Location and geology

The study area is near Beypazari town that is 100km northwest of Ankara, and the Beypazari natural soda (trona) field is located in an area of 8 km², which is 20 km northwest of Beypazari town center (Fig. 1)

Beypazari natural soda (trona) field exists in the lower parts of the volcano-sedimentary sequence of the neogene basin and characteristically comprises no outcrops. The elevations
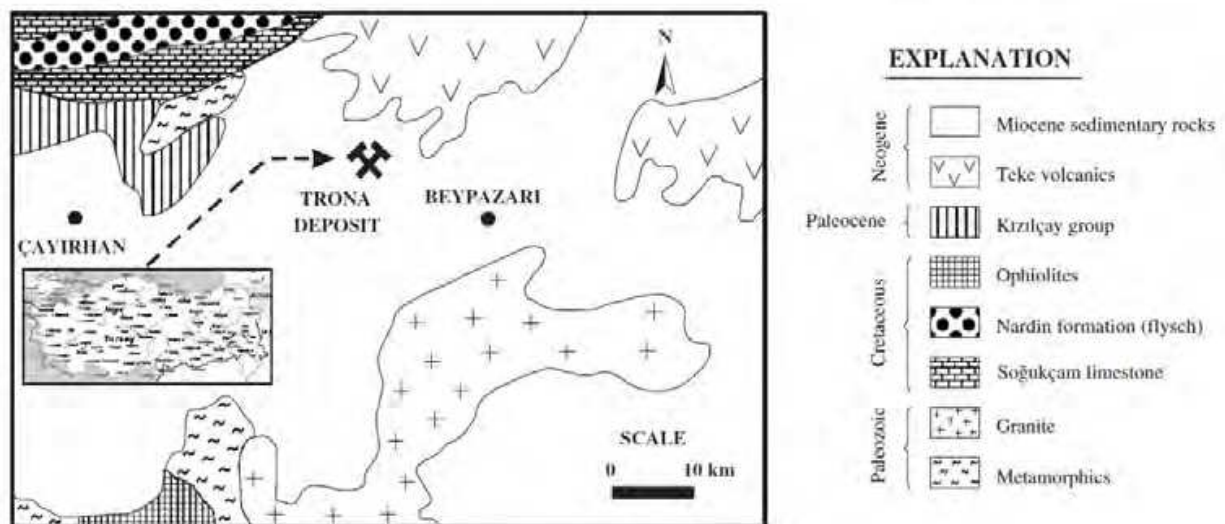
Fig. 1. General geology and location map of the study area (from Helvaci; Helvacı et all, 1989; Aksoy et all,2006).

in the Beypazari Neogene basin change between 800 and 1100 m and there is often a smooth morphology in this area. Continental climate dominates the region and there is no active stream system present there. The Neogene rock units are dominantly precipitated in shallow pond domain. The probable source of the Na ion required for the accumulation of trona deposit is the extended Neogene igneous rocks compacted with the sediments in the northeast of the basin. The Beypazari natural soda deposit is structurally confined by two fault systems and split by another fault system. Of those faults, the Zaviye fault has developed as a consequence of an extended tectonic regime affecting the region during the Lower-Mid Miocene. The Cakiloba fault is a folded series of an anticline– synclinal sequence. Its general orientation is N73E. This folding can also be described as a highly inclined monocline extending along NW–SE (Unal et all, 1997). The Kanliceviz fault splitting the trona deposit is generally oriented N20W and it has a dip-strike of 35–600 SW. It intersects the Zaviye and Cakiloba faults almost perpendicularly and has the character of an inverse fault(Figure 2.).

3.2 Laboratory studies

This study is divided into two sections: the first one includes identification of clay samples; the second one covers determination of the geotechnical parameters of the soft rocks and soda beds around the main drift. Rock types which occurred along the main drift line, based on thin sections and X-ray diffraction analyses, which were carried out in accordance with the methods described by the ISRM. Different block samples obtained from the tunnel face have been used in this study. The test results are summarized in Table 1.

The study area consists of two different soda zones with intermediate bands in between. The upper zone includes six separated soda beds. The dominant soda mineral in U1 and U2 is nahcolite; U3 is combined of trona and nahcolite; U4–U5 and U6 consist of mainly trona minerals. Since the natural soda bed U2 is too weak and thin, reliable results could not be obtained. While limited numbers of tests were carried out for the U1 and U3 beds, detailed tests have been conducted for the U4, U5 and U6 beds.
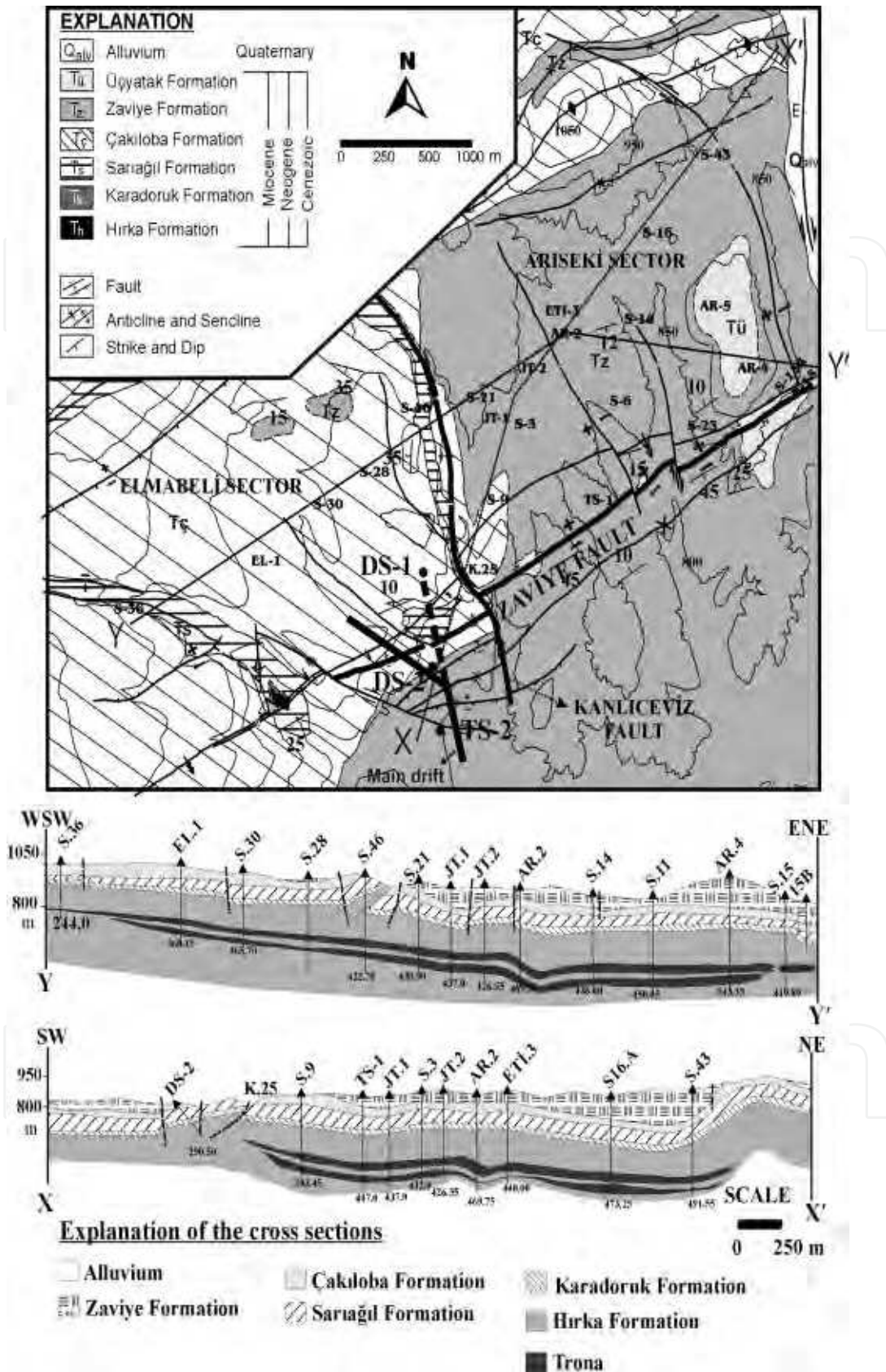
Fig. 2. Geological map and cross-sections of the Beypazari natural soda field (Onargan et all, 2004).

Engineering properties	Unit	Hanging walls	Soda beds
Unit volume weight	Kg/m^3	1960–2500	1820–2410
Porosity	%	1.61–11.71	0.47–2.35
Water content, ω	%	6.69–21.22	—
Slake durability, I_{d2}	%	11.24–69.56	6.7–32.60
Point load index, I_p	MPa	0.29–1.33	0.46–1.81
Uniaxial compressive strength, σ_c	MPa	6.9–32.02	5.0–46.2
Young Modulus, E	MPa	900–14800	900–26100
Cohesion, c	MPa	0.29–3.3	0.90–8.60
Internal friction angle, ϕ	(°)	42–65	48–63

Table 1. Geomechanical properties of hanging walls and soda beds (Onargan et all, 2004).

The geomechanical properties show great variety in the soda-bearing-bituminous shale formations due to the soda content. Two graphs illustrating the mechanical strength and deformability values obtained for the waste rocks and soda beds are given in Fig. 3. As seen in these diagrams, both the soda beds and waste rocks show a broad range of deformation properties, varying from ''very weak'' to ''medium'' characteristics.
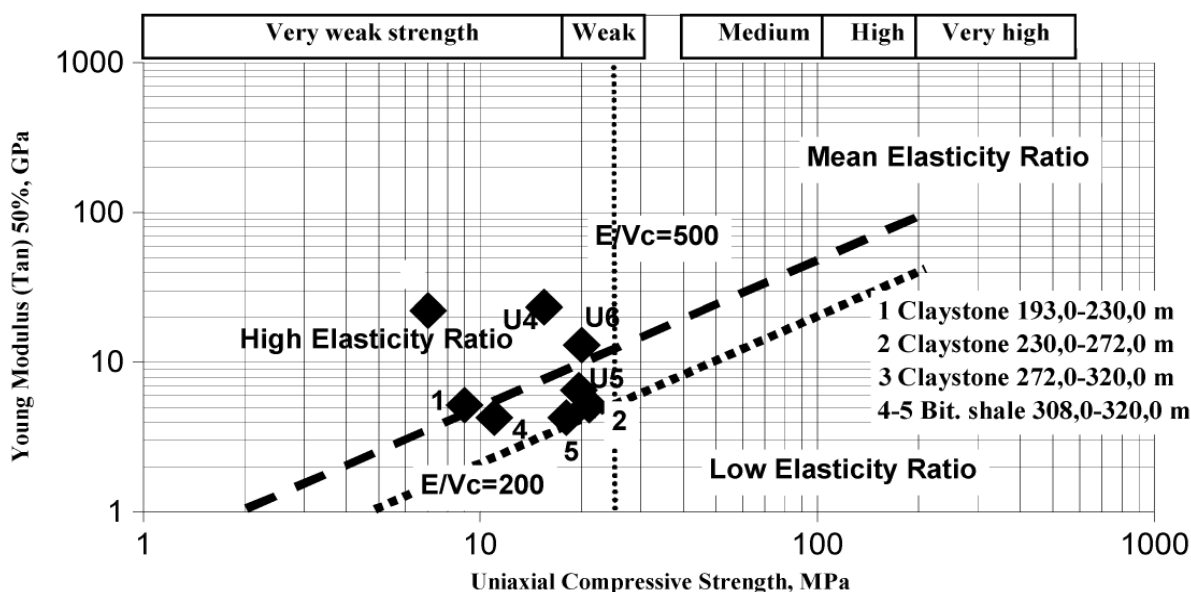

Fig. 3. The relation between uniaxial compressive strength and Young's modulus for the soda beds and waste rocks (Onargan et all, 2004; Onargan et all, 2001).

3.2.1 Creep test results

The time-dependent deformation of trona, or creep, consists of four stages, namely: an elastic deformation stage, a transient or primary creep stage, a steady state or secondary creep stage, and a tertiary creep stage. The instantaneous elastic deformation occurs immediately after the creation of an excavation and is followed by the primary creep stage.

In this primary creep stage, a high deformation rate decreases exponentially with time. The exponential decrease of the deformation rate under constant load in laboratory creep tests can be described as a strain hardening effect.

In this study, the creep tests have been carried out to determine the deformability properties of rocks versus time. The samples were tested under a load equal to 75% of the uniaxial compressive strength at 20 ℃ room temperature. The deformability properties of clay Stone and trona beds (U4, U5, U6) versus elapsed time have been recorded. The creep properties of clay stone, U4 and U5 seem weaker when compared to U6. The clay stone, U4 and U5 ores complete the behavior of the 3rd creep region in 800–1000 min, while the U6 ore completes the same region in about 1400 min. (Figure 4.)

(a) Claystone   (b) Soda bed(U5)

(c) Soda bed (U4)   (d) Soda bed (U6)
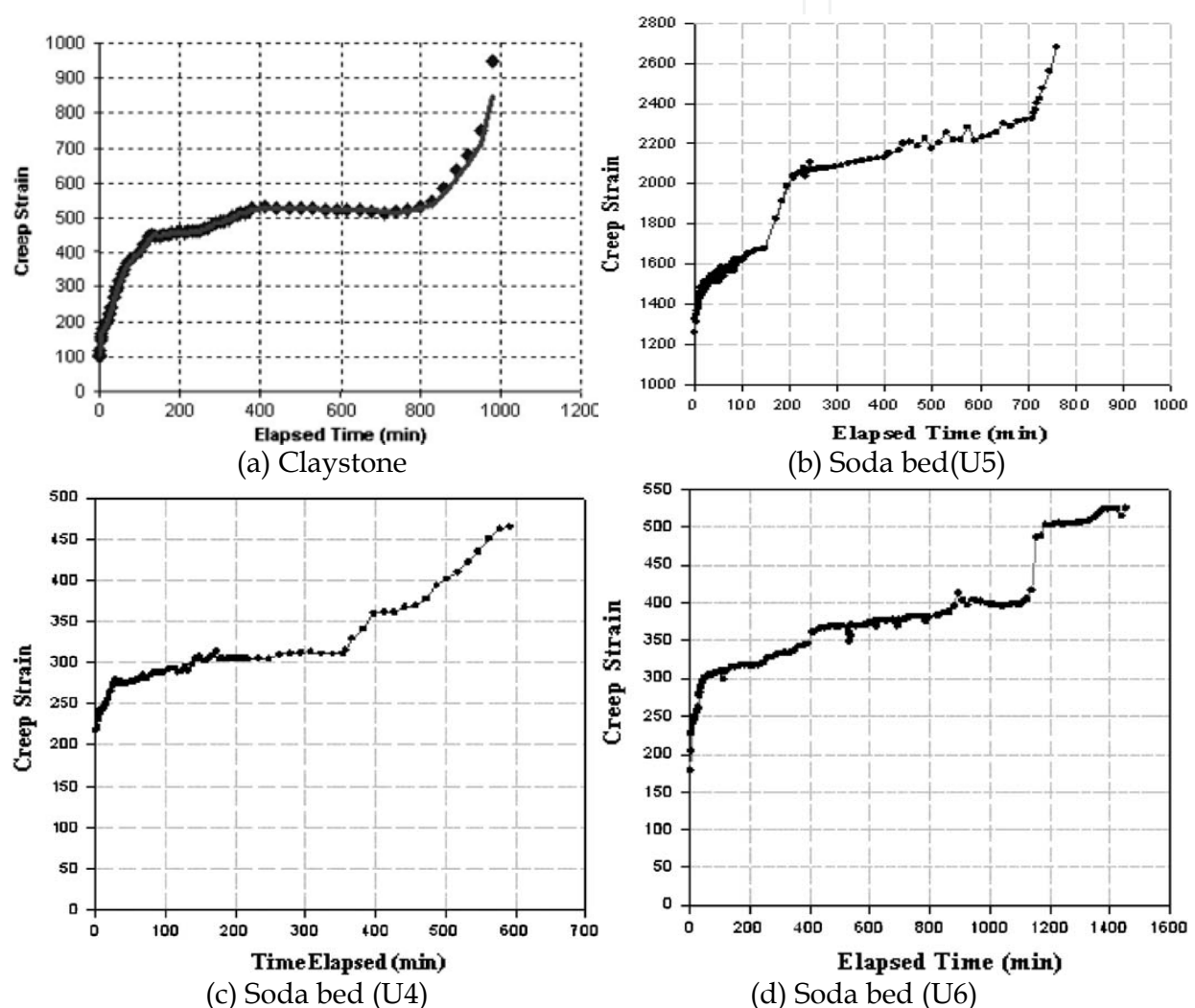
Fig. 4. Creep versus time for rock and soda samples(Onargan et all, 2004).

3.2.2 Atterberg limits and swelling tests

The dominating mineral within the clayey formations is montmorillonite accompanied by a trace amount of illite. The swelling properties of the intermediate clay bands and consolidated clay have been found as 4–18%. For the intermediate roof formation of U1, the swelling coefficient under pressure was found to be 7% as tested by the oedometer. This

clay formation is termed Lithology 2 in this study and the intermediate clayey band between U1 and U2 is termed Lithology 5. They both show the characteristics of CH type of clay. Therefore, these levels require special attention during the mine planning. Apart from these, the clay Stone between U2 and U3 are termed Lithology 8, Lithologies 11 and 12 between U3 and U4, and Lithology 21 taking part between U4 and U5, are all in the category of clays of high plasticity. Several tests, have been conducted for the predetermination of index values on the intermediate bands and hanging wall formations. These formations are made up of clay stones, and they show soil character due to the weathering and existence of water.

Atterberg limits of these clayey soils were determined by a procedure suggested by ASTM. The Liquid Limit values (LL) vary between 38 and 88 for clay and soft clay stones, while the Plastic Limit (PL) values are between 27.81 and 56.25 and the Plasticity Indices (PI) were found to be about 10–40. According to the Unified Soil Classification Systems (USC); these clays, are classified as CH, and they are also under the group termed ''Inorganic Oily Clays with High Plasticity''. In the tests applied to un-altered samples, the consolidation index and swelling index were determined as 20% and 7%, respectively. These kinds of soils are classified as ''high swelling potential soils'' by O'Neil and Poormoayed. Hence, it is foreseen that additional support precautions will have to be taken at the necessary positions in the underground openings.

3.3 Field measurements at the T-2000 main drift and T-3000 roadway

The Main Drift, T-2000, and a roadway, T-3000, were excavated for Beypazari trona (natural soda) underground mine project between the years 1999 and 2001. The instruments were installed at several underground monitoring stations in order to obtain the necessary in situ data regarding displacement, deformation of supports and load using the load cell system. The magnitude and orientation of the loads were analyzed according to the results of the in situ measurements. Rock pressure was determined by the in situ measurements of the deformation of the support.

Support load and convergence measurements were recorded daily for a period of about one year until the convergence rate decreased significantly. Six different stations were set up along the main entry drift for these measurements.

Load cells were placed at some of the points and the load increase over the support units was determined versus time. Three more stations (U4-a, U4-b and U4-c) in the roadway (T-3000) have been established within the soda bed (U4), again to determine the amount of load and convergence.

The stations in the main drift were coded as K-20, K-21, K-22, K-23, K-24 and K-25, which were all after the support installation. Vertical and lateral closures and narrowing were monitored daily for a period of 400 days.

3.3.1 Support loads

The support system load values were recorded by a digital gauge connected to the load cell system. The measured support loads at the stations versus time are plotted and shown in Fig. 6. According to these measurements, the support load at K-23 roof-rock station was found to be 0.09 MPa. At the U4-a station in the soda bed, the support load was 0.06 MPa.
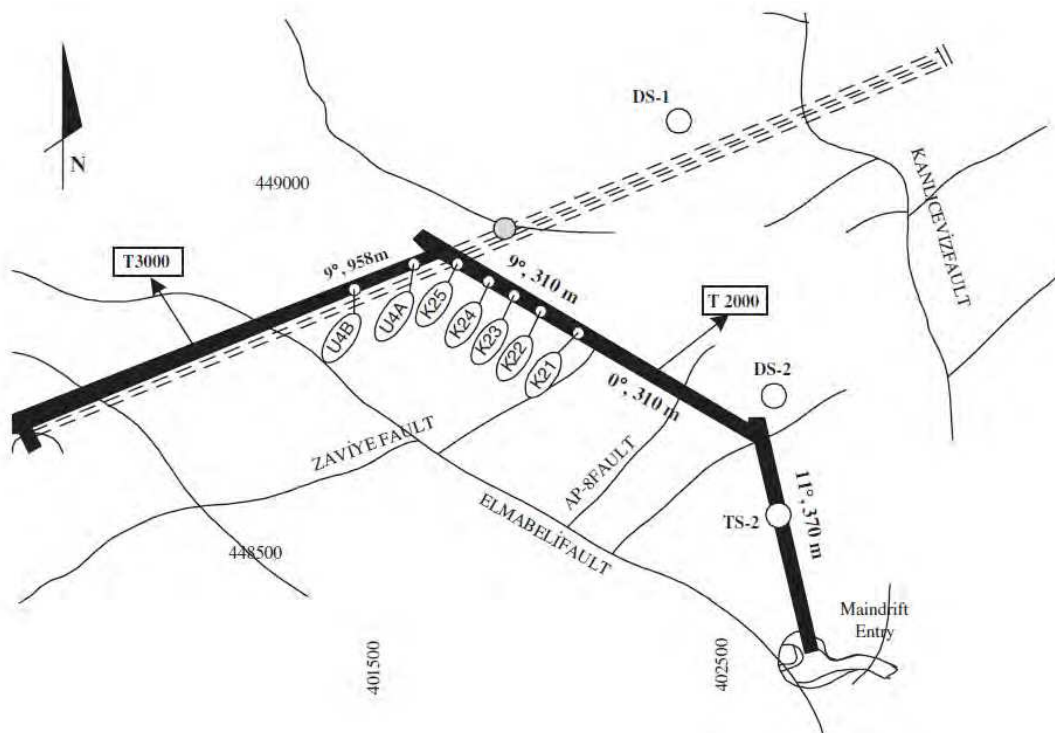
Fig. 5. Monitoring station and plan view of the main drift and underground openings in Trona mine (Onargan et all, 2004; Aksoy et all,2006; Onargan et all, 2001).

These values are quite close, because the strengths of the formations are similar and the spacings of the steel sets are also closely selected. For some locations, the support loads were measured as 0.31 and 0.24 MPa, respectively for the steel set intervals of 1 and 0.70 m.

3.3.2 Convergence monitoring

Convergence measurements at the main drift revealed variations in measured values over long periods of time. These values are independent of the face advance. Nine measuring stations were considered suitable for the analysis of the measured data. In these stations, horizontal and vertical convergences were measured between points of the rock wall.

This measurement system is illustrated in Figure 7 and 8. Between the tunnel length of 679 and 813 m, the main drift was driven in clay stone, bituminous shale, volcanic tuff and tuffitic claystone. In this part, 'rigid arches' were used as the supporting system by the management. For this section of the drift in the clayey formation, two kinds of problems were faced. Firstly, large deformations took place. Secondly, considerable swelling was observed, which was expected in the silty clay formations as mentioned before.

Floor heaving due to swelling capacity of the weak formation was also observed. The convergence measurements were performed using a tube-extensometer. The details of these measurements can be found in the research report(Onargan et all, 2001). All the resulting values indicate that deformations were below 1% on the convergence measurement lines Similar tests, for all the stations chosen, were carried out in different formations. Results can be seen in Figs. 9 and 10 in graphical form. It can be deduced from the foregoing studies that the total convergences at all the stations were found to be below 1% of the total gallery height and deformation rates were reduced significantly.
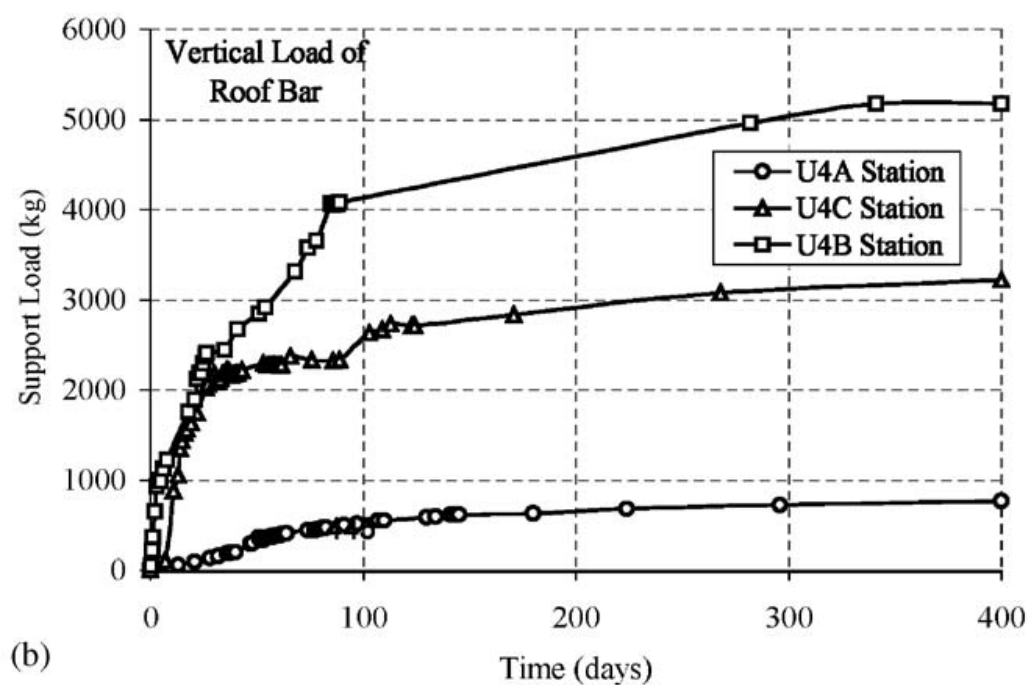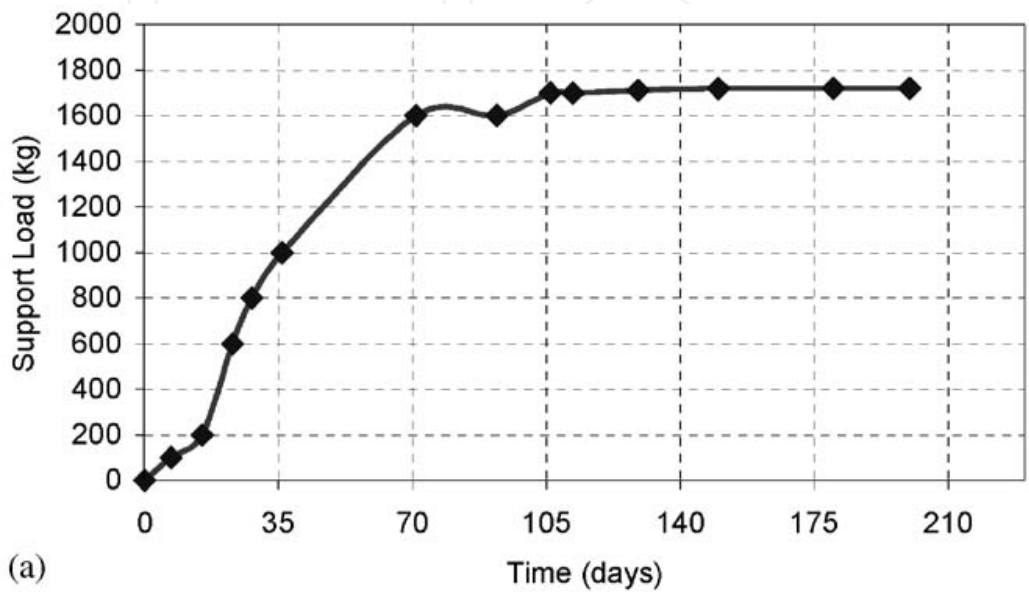
Fig. 6. Support loads versus time at soda beds and roof rock stations: (a) roof rock station (Station number: K-23) and (b) soda beds stations. (Onargan et all, 2004).
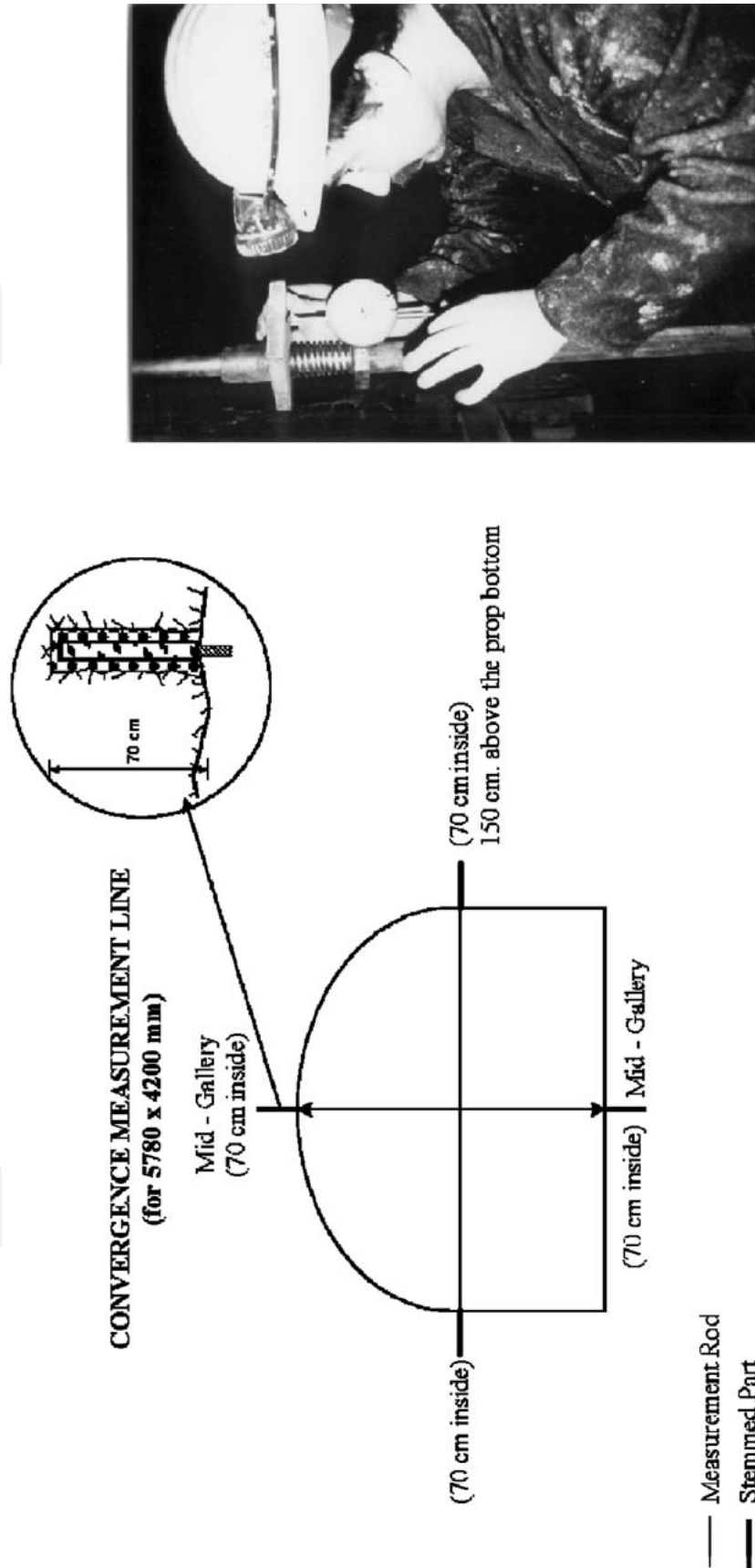
Fig. 7. Lines and intervals of convergence measurement at the stations(Onargan et all, 2004).
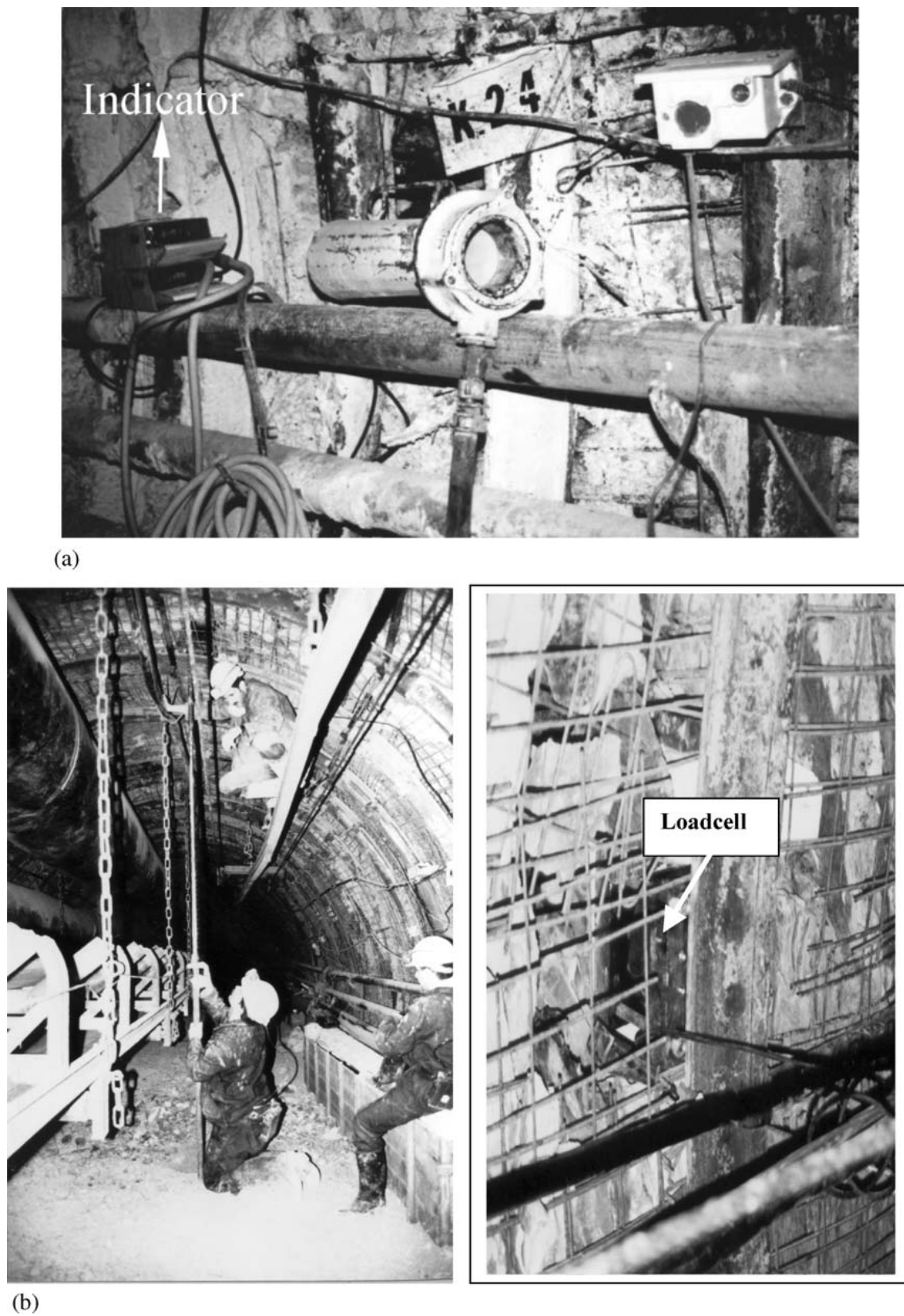
Fig. 8. Some views of the measurement stations in the hanging-walls: (a) a view of the station (K-24) and (b) convergence and support load measurement studies(Onargan et all, 2004).

In order to study the behavior of the support system, the convergence measuring stations were installed in the roadway (T-3000) driven in the soda bed. This roadway was driven with a 18 m2 cross section, using yielding steel sets of 29 kg/m TH profile with several spacings. These stations are termed U4-a, U4-b, and U4-c and convergence measurement and support loads were measured daily over a period of 400 days. As can be seen from Fig. 10, the maximum vertical closure was recorded as 198 mm, 5% of the original roadway height at the U4-a station. The values were obtained as 340mm (8.5%) at U4-b, and 198mm (5%) at U4-c for the other monitoring stations.
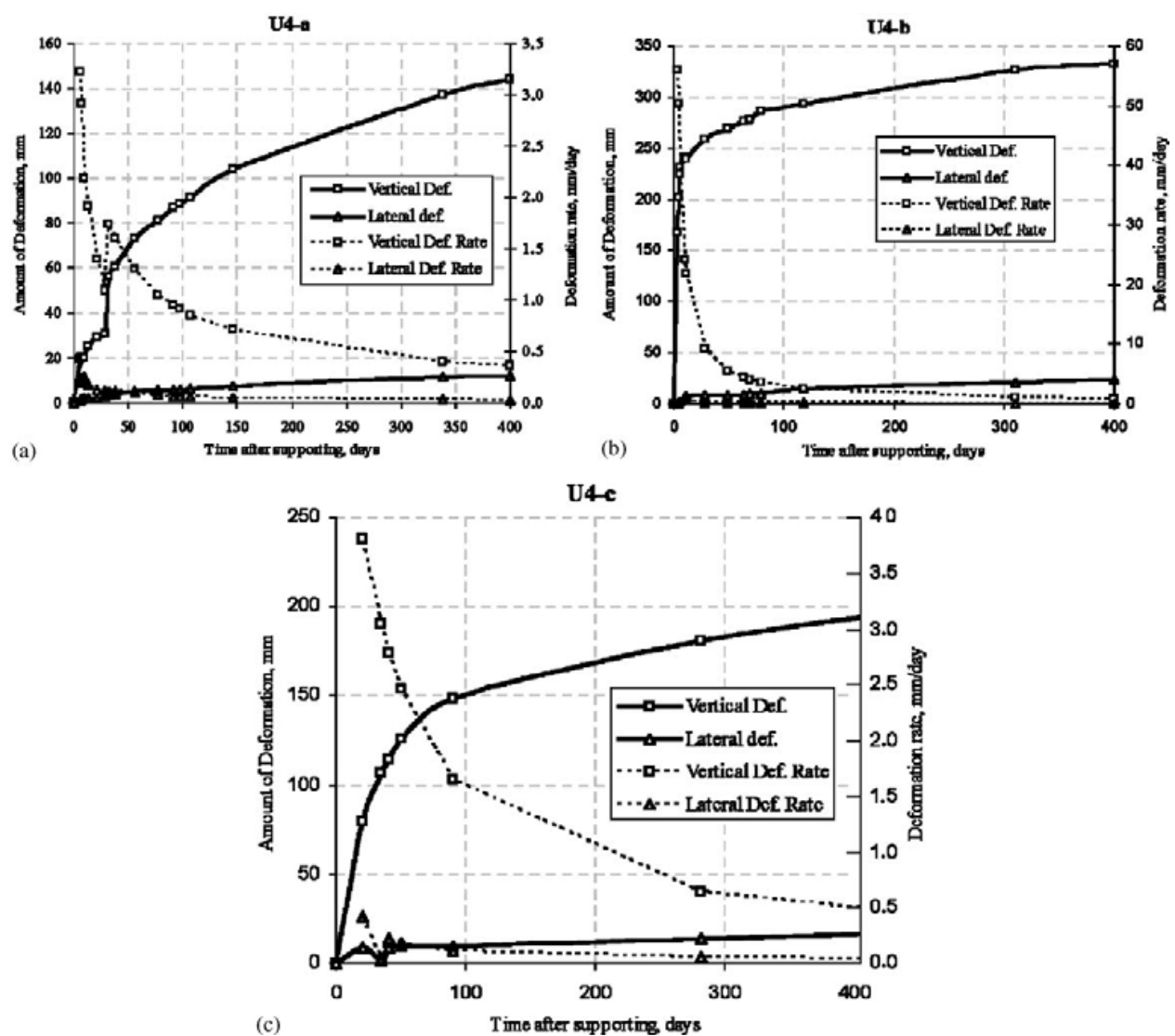
Fig. 9. Convergence versus time at the soda beds: (a) U4-a station (Steel set spacing 0.5 m), (b) U4-b station (Steel set spacing 1.00 m) and (c) U4-c station (steel set spacing 0.70 m). (Onargan et all, 2004).
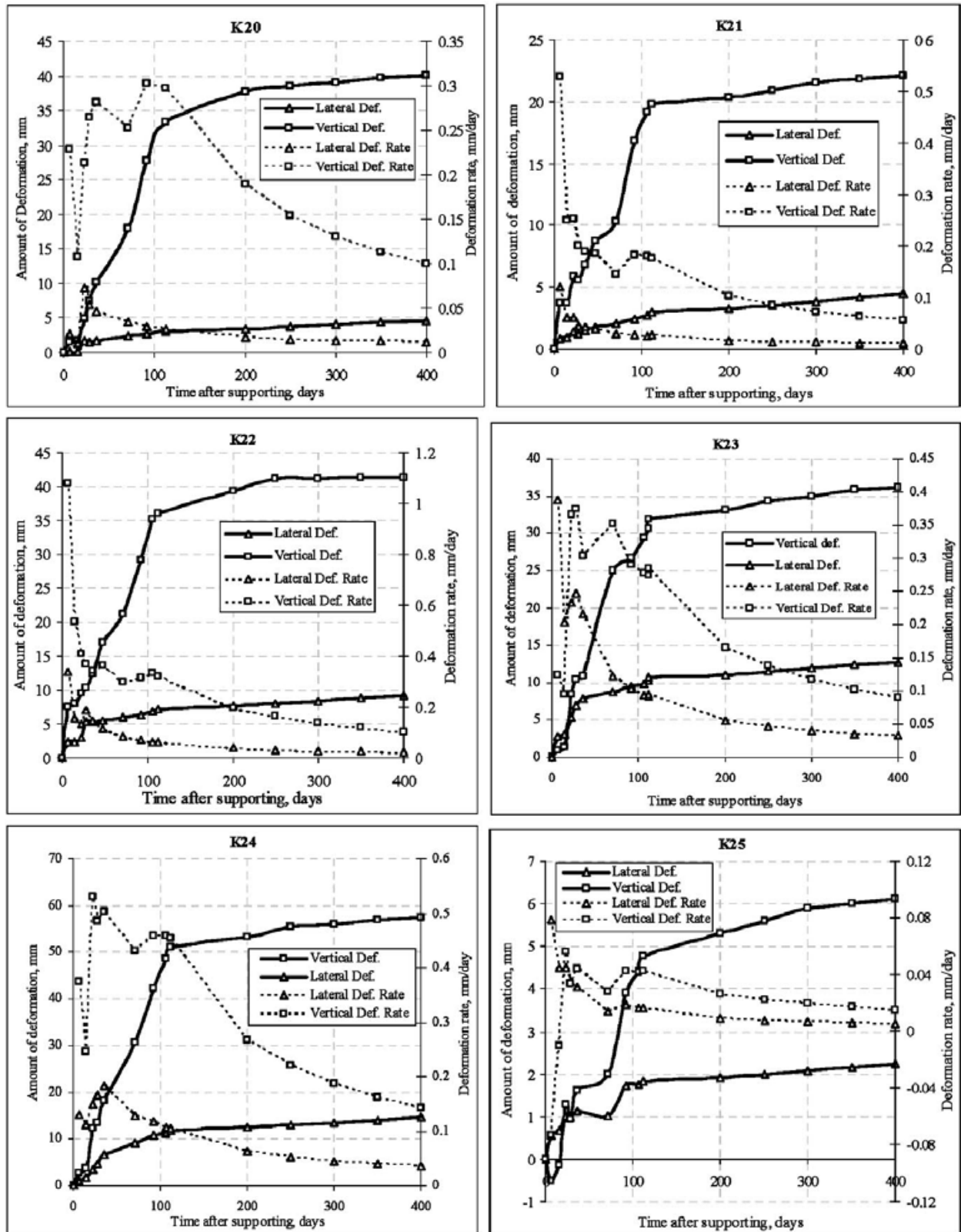
Fig. 10. Convergence versus time at the hanging wall stations (Onargan et all, 2004).

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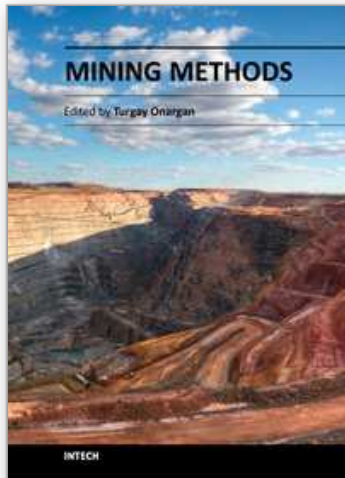
Mining Methods

Edited by Prof. Turgay Onargan

An economic viability of a modern day mine is highly dependent upon careful planning and management. Declining trends in average ore grades, increasing mining costs and environmental considerations will ensure that this situation will remain in the foreseeable future. This book describes mining methods for the surface and underground mineral deposits. The methods are generalized and focus on typical applications from different mining areas around the world, keeping in mind, however, that every mineral deposit, with its geology, grade, shape, and volume, is unique. The book will serve as a useful resource for researchers, engineers and managers working in the mining industry, as well as for universities, non-governmental organizations, legal organizations, financial institutions and students and lecturers in mining engineering.

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