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Expansive Shale Damage, Theban Royal Tombs, Egypt

L'Argile Expansif Dommage, Vallée des Rois, l'Égypte

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SYNOPSIS Rock-cut tombs of ancient Egypt's greatest pharaohs are crumbling under the combined assaults of Man and Nature. This progress report of the Brooklyn Museum's Theban Royal Tomb Project (TRTP) summarizes three season's work in the Valley of the Kings, describes the geological setting of the Valley, and analyses the effects of rock movement on the tombs. The final section evaluates the destructive forces acting on the tombs and outlines protective measures which will prolong the life of these historic and artistic legacies of a great civilization.

INTRODUCTION

The Valley of the Kings, a remote desert wadi penetrating the limestone cliffs along the west edge of the Nile floodplain opposite the modern city of Luxor, Egypt (Fig. 1), is the site of at least 68 tombs of the 18th, 19th and 20th Egyptian dynasties, including 24 inscribed with the royal cartouche or containing other identification of Egyptian kings (Thomas, 1966).

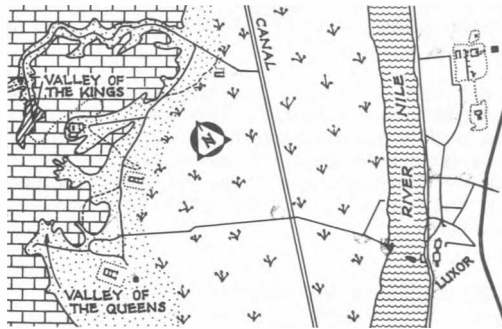


Fig. 1 Theban Necropolis, Luxor, Egypt

From 1550 B.C. to 1100 B.C. a small settlement of engineers and artists cut, plastered, carved and painted limestone chambers as long as 175 meters sloping to a maximum depth of 100 m. below the entrances. The painted relief constitutes some of the finest examples of New Kingdom art and the carved religious texts are an irreplaceable source of information.

In 1975 the Brooklyn Museum's engineering consultants discovered evidence of relatively rapid tomb deterioration, which was reported to the Egyptian Service of Antiquities (Romer, 1977). The Museum organized a team of Egyptologists, epigraphers, photographers, artists, geologists, architects and engineers called the Theban Royal Tomb Project (TRTP) to record and evaluate the condition of the royal tombs.

During three seasons of field work, the TRTP located 62 tombs in the Valley of the Kings. 25 of these were filled with debris, 12 were otherwise inaccessible and one was not examined internally. Members of the expedition examined the remainder of the tombs internally and identified the following sources of damage to the tombs:

1) Manmade

- o Damage during tomb clearing.
- o Creation of unstable tailings dumps above the tomb entrances.
- o Alteration of natural topography by construction and tailings disposal.
- o Discharge of liquid waste near expansive shales.
- o Use of tombs as debris dumps
- o Theft
- o Vandalism
- o Accidental damage by tourists
- o Increase of internal tomb humidity caused by tourist overcrowding.
- o Rock dust abrasion caused by tourist traffic.

2) Natural

- o Flood-caused shale expansion
- o Rainfall-caused rock joint widening
- o Flood-borne debris abrasion
- o Salt crystal formation
- o Natural weathering

This paper describes the two greatest natural sources of tomb damage 1) expansive shale movement and 2) rock joint spreading, both caused by intense rainstorms.

THE GEOLOGY OF THE VALLEY OF THE KINGS

As described by the TRTP geologists (Curtis, 1979), the strata forming the cliffs and hills surrounding the Valley of the Kings and the Valley of the Queens are almost flat-lying and are composed of two rock types, marine limestone and shale. (Map, Fig. 2) The rock types occur principally in two formations: a lower, the

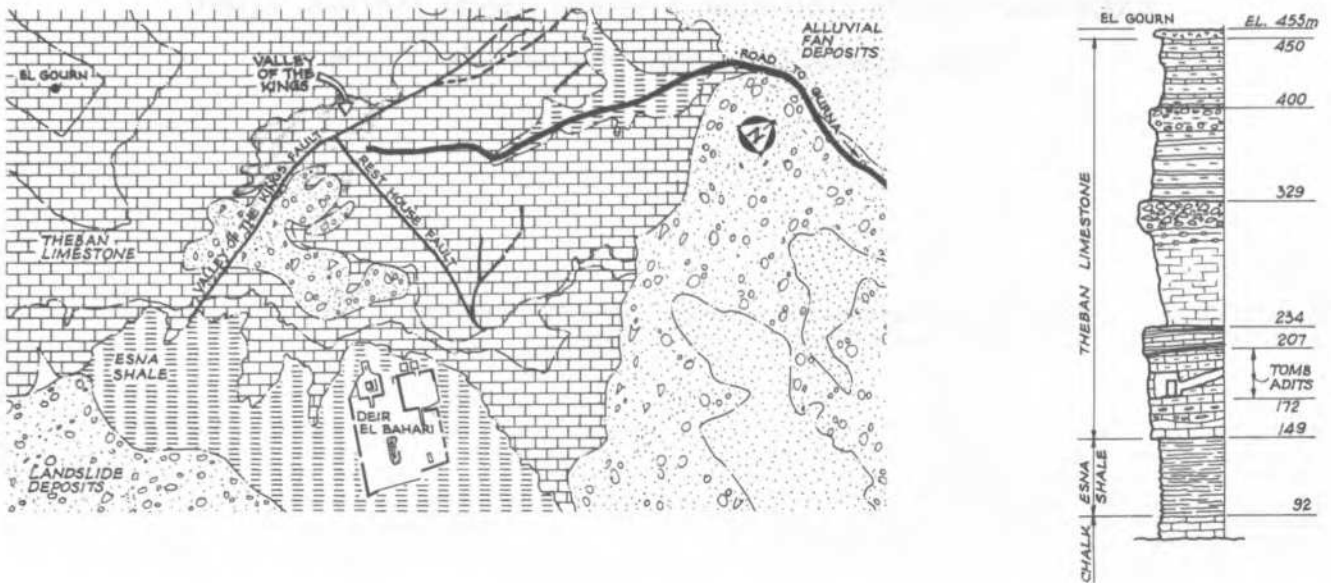


Fig. 2 Geologic Map of the Valley of the Kings and Stratigraphic Section

Esna Shale; and an upper, the Thebes Formation. Both are of Lower Eocene age (Ypresian), although there are a few small outcrops of an underlying limestone, "Chalk," possibly of Paleocene age, in Deir el Bahari. The Esna Shale is approximately 58 m. thick in Deir el Bahari and is essentially uniform throughout, although in its upper few meters, it is interbedded with thin limestone beds. The Thebes Formation is 300 m. thick as measured from the top of the Esna Shale in the Valley of the Kings to the highest beds exposed on el Gourn, but there may be higher members in hills to the west of el Gourn. The Thebes Formation can be divided into several distinct members and beds of limestone and shaly limestone which maintain their lithologic characteristics well throughout the area. It is in the lowest marly limestone bed of the lowest member of the Thebes Formation that all of the entrances of the royal tombs have been cut, although some of the tombs descend into the underlying Esna Shale Formation (Stratigraphic column, Fig. 2).

The basal member may be divided into four lithozones which grade into each other and are not sharply separable, but characteristic differences are discernable that serve to identify them in the walls of the tombs and in surface exposures. There is progressively less montmorillonitic clay upward in these lithozones, and the uppermost, thinly laminated zone, is rich in silica and very resistant to erosion. It forms the prominent flat-topped cliff surrounding the Valley of the Kings.

Following uplift in later Tertiary time and down-cutting by the Nile River, a steep topography was developed in these beds. Erosional processes yielded two new types of deposits from these older formations. Landsliding on a gigantic scale produced deposits of brecciated Thebes Formation that extend outward from the steep cliffs of limestone and shale north of Deir el Bahari and the Valley of the Queens for a distance of more than a kilometer toward the Nile in some localities. Subsequent to the formation

of most of these landslide deposits possibly of early Pleistocene age, fanglomerates, conglomerates, sands, and in some cases, fresh water limestone, were deposited over the top of the landslide breccias to a thickness of 70 m.

These landslide and fanglomerate deposits appear to have resulted from changes in climate over the past two or three million years, alternating from very wet to dry to wet to arid, today's climate in this area. In the wet period that preceded today's arid climate, the present canyons were cut.

Several small faults cut the strata but have not been active in historic time. The largest of these has a displacement of 30 m. Vertical rock joints are prominent in many places and were often used by ancient tomb excavators to start their entrances, as they gave free surfaces to break to.

EXPANSIVE SHALE MOVEMENT

Over the past 3500 years several royal tombs have repeatedly been penetrated by flood-borne debris arising from infrequent but intense desert rainstorms in a region where the annual rainfall is less than 1 centimeter (Romer, 1979). Some tombs have undergone at least 7 flood events (Monaghan, 1979) and a few have never been completely cleared (Fig. 3). Tests of samples of interbedded shale taken from this tomb show a plasticity index of 41 and 12.5% swell at 0.25 kg/cm² load. Where tomb excavation extended to Esna Shale or to the interbedded shales in the lower Theban Limestone, flood waters saturated the highly expansive rock units and caused damage ranging from minor cracking to total collapse of pseudo-structural partitions and columns as shown in the mechanism sketched in Fig. 4.

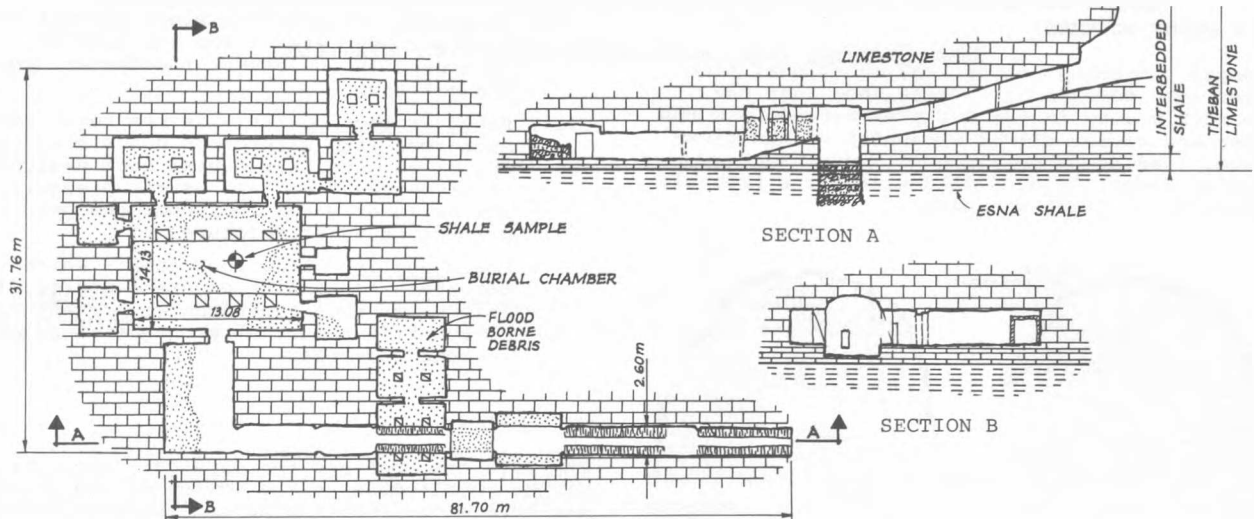
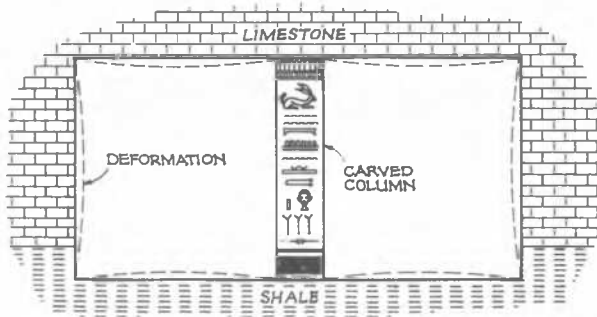
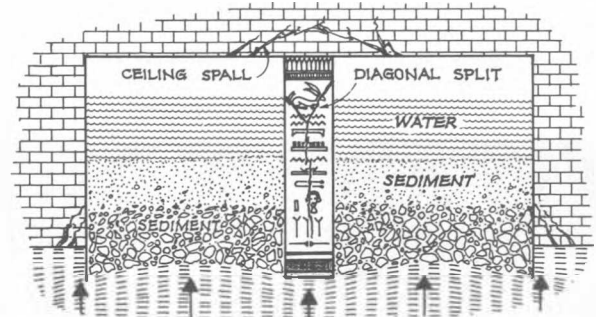


Fig. 3 Plan and Sections, Tomb of Ramesses II



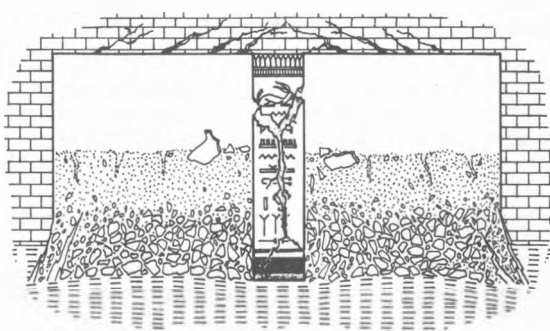
PHASE 1: INITIAL EXCAVATION

Overburden pressures on rock excavated for tomb chamber exceeded $300,000 \text{ kg/m}^2$ in some cases. Minor deformation and overbreak occurred during stress redistribution following excavation.



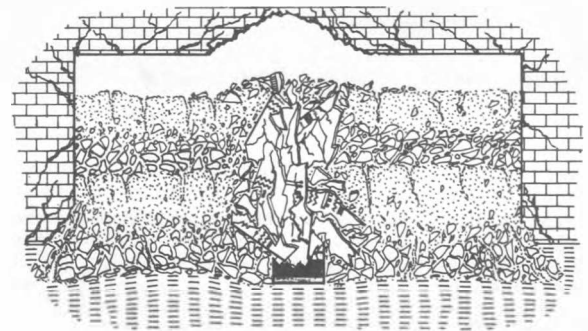
PHASE 2: FLOODING AND SWELLING

Flood-saturated expanding shales exert enormous upward force on rock pillars and partitions, splitting walls and columns.



PHASE 3: DESICCATION

The drying shale slowly shrinks, leaving portions of broken columns and walls hanging from the roof structure.



PHASE 4: COLLAPSE

After several flooding and drying cycles the ceiling spalls and hanging members drop into the flood debris.

Fig. 4 Flooding and Expansion Mechanism

ROCK JOINT MOVEMENT

Widened limestone joints lead occasional rain-water into some tombs. Tests show that the expandable clay in the marly limestones absorbs water and causes slight expansion of the limestone, leading to spalling of carved and painted tomb surfaces. Fig. 5 illustrates the probable mechanism of crack widening.

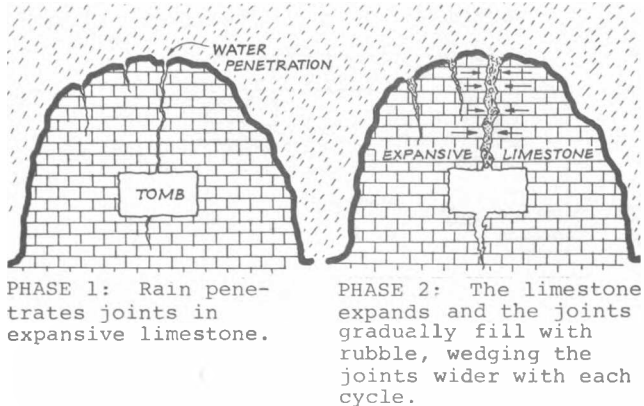


Fig. 5 Rock Joint Widening Mechanism

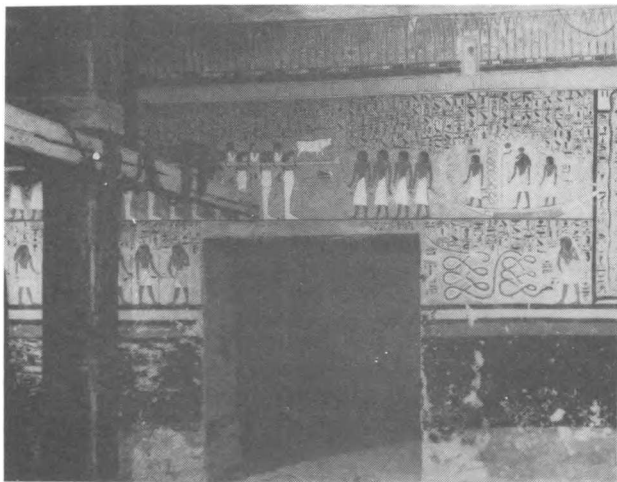


Fig. 6 Burial Chamber, Tomb of Ramesses I

PRELIMINARY RECOMMENDATIONS

Several important royal tombs, including the magnificently decorated chambers of Ramesses II and Ramesses III, have already been largely destroyed by flood-induced rock expansion and joint spreading. Several other tombs in the Valley of the Kings, including those of Tutmosis III, Tutankhamen and Seti I, will eventually be destroyed from flood damage.

Although the catchment area is relatively small in size, major floodwater detention and diversion cannot be constructed without threatening other tombs in adjacent wadis. The TRTP has included the following tomb flood protection recommendations in the preliminary report:

- (i) Diversion Construct a minor channel in the catchment area above the tomb of Tutmosis III to divert floodwater from the entrance.
- (ii) Flood Protection Provide the royal tomb entrances with waterproof doors consisting of an outer structural door designed to withstand flood and debris pressures and an inner waterproof door designed to prevent entry of moisture.
- (iii) Crack Sealing Seal rock joints which penetrate tombs with concrete and/or flexible waterproof membranes to prevent entry of runoff and further propagation of cracks in tomb chambers.

CONCLUSION

The TRTP has analyzed the physical deterioration of the royal tombs in the Valley of the Kings and determined that the major causes of damage are flood-induced rock expansion and joint movement. Field investigation, rock testing and historical research have disclosed the damage processes. Simple and relatively inexpensive methods of tomb protection can preserve these unique museums of an ancient culture for hundreds of years to enlighten scholars and delight the casual tourist with views of the hereafter such as that shown on Fig. 6.

ACKNOWLEDGEMENTS

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