# The Why, How, and When of the Siloam Tunnel Reevaluated

AMIHAI SNEH
Geological Survey of Israel
30 Malkhe Israel Street
Jerusalem 95501, Israel
sneh@gsi.gov.il

RAM WEINBERGER
Geological Survey of Israel
30 Malkhe Israel Street
Jerusalem 95501, Israel
rami.weinberger@gsi.gov.il

EYAL SHALEV
Geological Survey of Israel
30 Malkhe Israel Street
Jerusalem 95501, Israel
eyal@gsi.gov.il

*The Siloam Tunnel, an important engineering achievement of the Iron Age II, led the water of the Gihon Spring inside the city perimeter of ancient Jerusalem, ensuring water supply in peacetime as well as during war. This enterprise was planned after an earlier aqueduct failed to adequately supply Jerusalem's water needs because of hydrological limitations; also it was insufficiently defensible. We hypothesize that the tunnel was hewn at a level close to that of the local groundwater, along a natural winding route of interconnected karstic cavities developed in fissures and in dipping bedding planes. Because of the time needed to complete the project (we estimate at least four years), it could not have been undertaken as a countermeasure to the Assyrian king Sennacherib's siege in the year 701 B.C.E., nor could it have been completed before King Hezekiah's death in 698 B.C.E. We therefore suggest that it was carried out by Manasseh, King of Judah, at the beginning of the seventh century B.C.E.*

## INTRODUCTION

Ancient Jerusalem's increasing demand for water to supply its growing population gave rise to the construction of waterworks utilizing the main water source in the area, the Gihon Spring. The most impressive waterwork in Jerusalem of the first millennium B.C.E. is the Siloam Tunnel, a 533-m-long tunnel winding from the Gihon Spring toward the Siloam Pool at the Tyropoeon Valley at the southern tip of the City of David (fig. 1).

The Siloam Tunnel was simultaneously cut from both north and south; it measures about 0.60 m wide and slightly less than 2 m high, except in its southern 50-m-long sector, which exceeds 5 m in height (Vincent 1911: 19, 42). Based on archaeological findings and interpretations of biblical texts, until now this enterprise has been attributed to the eighth century B.C.E., which corresponds to radiometric age determinations by Frumkin, Shimron, and Rosenbaum (2003), who confined the Siloam Tunnel age to First Temple times, ruling out the Hasmonaean period as proposed by Rogerson and Davies (1996). The Siloam Tunnel was preceded (Reich and Shukron 2007: 145) by the "Siloam Channel" waterwork (fig. 1; Channel II in fig. 2), which comprises two parts (Schick 1891). The northern part is a stone-covered channel that conveyed the Gihon water 190 m southward; its floor level is 2.38 m higher than the Siloam Tunnel's floor (Weill 1947: 73). Consequently, to enable a regular flow of water in the channel, a damming wall was built (Wall i in fig. 2, after Vincent and Steve 1954: pl. 62), blocking the

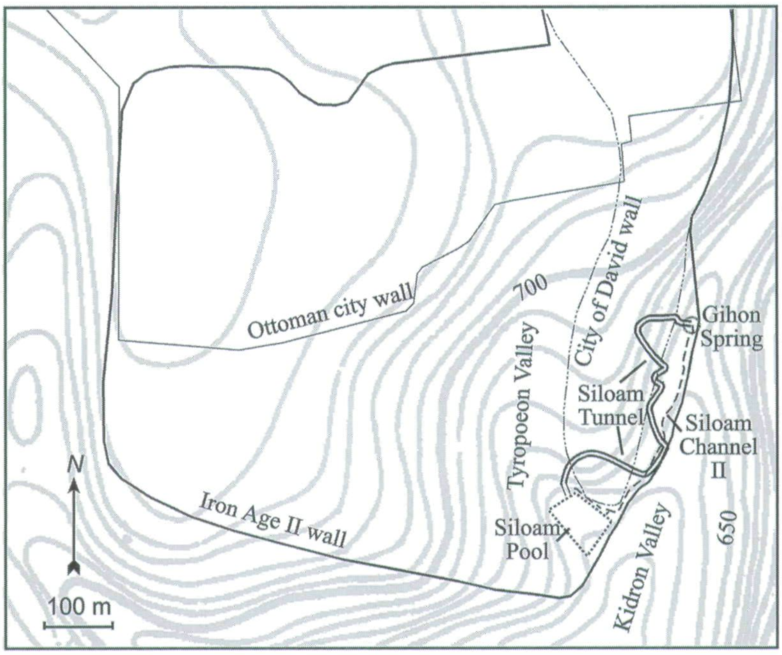

**Fig. 1**. Iron Age II Jerusalem and the City of David: plan view of the Siloam Tunnel, the Siloam Channel, and the Gihon Spring. Topographic contour interval: 10 m. Based on Avigad (1983: 58, fig. 36), Shiloh (1984), Reich and Shukron (2002a), and the Survey of Israel.

natural drainage toward the Kidron Valley. The southern part is a rock-hewn tunnel that continues the channel that led the water farther south down to the southern tip of the city toward the Siloam Pool. According to Reich and Shukron (2002a; 2004), the northern channel is Canaanite and is dated to the Middle Bronze Age. Close to the spring, it is connected via Tunnel III to a rock-cut pool (fig. 2) of the same period; from here, water could be raised up onto a "cave," linked via a sloping underground passage to the city. The southern part is Israelite, dated to the eighth century B.C.E.

Before the new findings about the earlier Canaanite waterwork were exposed by Reich and Shukron (2002a; 2004), "Warren's Shaft" (fig. 2) was thought to be a Canaanite 13-m-deep well from which water was raised onto the sloping passage. However, according to these investigators, as the shaft's top was opened only in the eighth century B.C.E. and was not known beforehand, it obviously could not have functioned as a waterwork in the Middle Bronze Age. Based on examination of its irregular walls, Gill (1991; 1996) concluded that, in fact, this shaft is a natural karstic sinkhole developed along a fissure.

The archaeological aspects of the waterworks have attracted attention and have been thoroughly studied since the 19th century. Many investigators argue that the whole enterprise is the outcome of an engineering plan that was modified as circumstances changed. According to a recent article by Reich and Shukron (2007), this plan took into account geological elements such as fissures but was not guided by known continuous natural cavities. In contrast, Gill's geological studies (1991; 1994; 1996) support an earlier assessment (Sulley 1929; Amiran 1976; Issar 1976) according to which the tunnel follows a natural karstic conduit widened by quarrying. We find the latter approach more plausible but still find that the exposition of the facts presented so far leaves gaps to be filled and issues to be tackled and clarified.

## HYDROGEOLOGICAL BACKGROUND

Jerusalem's ground terrain over the 10-$km^2$ recharge area of the Gihon Spring (calculated by the authors based on Picard 1956) is typically karstic, with surface exposures of Cenomanian and Turonian limestones and dolostones overlying Cenomanian marls in the subsurface. Hydrologically, this geological setting results in a perched aquifer, with groundwater flowing eastward. All rock formations in the area generally dip 10°–15° east–southeast. (For a detailed geological

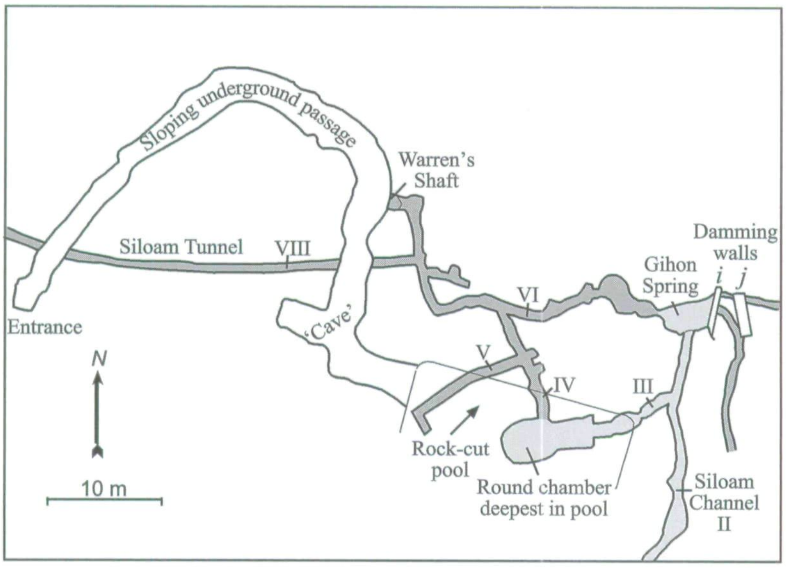

**Fig. 2**. The waterworks installations close to the Gihon Spring, based on Vincent and Steve (1954: pl. 62) and Reich and Shukron (2004). Aqueducts are marked by Roman numerals. Dark gray = water level at spring elevation. Light gray = raised water level.

map and a geological cross section, see Gill 1996.) The average annual discharge of the Gihon Spring is about 600,000 $m^3$. It is a perennial karstic spring with seasonal fluctuations, which in rainy seasons (December to May in 9 out of 14 years from 1979 to 1993) discharges more than 85 $m^3$ per hour and in dry seasons maintains a continuous flow of about 60 $m^3$ per hour (Hydrological Yearbooks of Israel 1979–1993). Until the last century, reports described the spring as having water gushing intermittently once every several hours during winter and once a day or less during the dry season (Warren and Conder 1884: 365–71; Vincent 1911: 37; Simons 1952: 163–66). The current high discharge of water throughout the whole year makes it reasonable to assume co-occurrence of a continuous flow in the past as well, topped by the spring gushes. Intensive urban development in modern times has caused a significant runoff, and water that used to infiltrate in lapies-shaped surfaces recharging subsurface voids now gets lost to the groundwater system, terminating the occurrence of intermittent gushes which used to characterize the spring in the past.

## WHY WAS THE SILOAM TUNNEL CONSTRUCTED?

The purpose of both enterprises—Channel II ("Siloam Channel") and the Siloam Tunnel—was the same: to securely bring as much of the spring's water where it was most needed, supplying domestic, farming, and gardening demands (Mazar 1995; Ussishkin 1994). Given the presence of Channel II, why was Siloam Tunnel needed?

In its natural state, Gihon Spring's emanation point is approximately at the same elevation as the nearby local groundwater level. As the spring's waters are not under pressure (e.g., as they are in an artesian well), when the water level was raised behind a damming wall (fig. 2, wall i) at the spring's site to force the outflow of water through the higher-lying Channel II, this caused greater subsurface sideways flow in karstic cavities away from the spring area, which in turn decreased the amount of water that was able to reach Channel II. This hydrological failure apparently was not especially noticeable when there were repeated gushes. However, during the long dry season when the basic discharge of the spring was relatively low and the number of water bursts was less than one a day, that water loss was very significant. The Canaanite waterwork, which had to supply water to a very small community, could have functioned adequately; the upgraded one, however, comprising the southern, eighth-century B.C.E. tunnel of Channel II, could not have operated effectively. Additional water losses could have occurred due to water infiltration through the floor of Channel II, yet this could be easily remedied, if necessary, by plastering. Around the mid-eighth century B.C.E. and onward, Jerusalem underwent a dramatic demographic change, expanding from a population of about 1,000 people before the Israelite period to a sizable town of about 12,000 (Finkelstein and Silberman 2006: 121–49). Given that population growth, the effect of the hydrological system, forcing water to rise, must have been crucial. As population growth continued rapidly, so did the water demand. Tsuk (2008) estimates water consumption at 5 $m^3$/year per capita in antiquity but agrees that where there was a rich water source, consumption would have been higher. In addition, he calculates water consumption at 32 $m^3$/year per capita when livestock was included and estimates that only half the population had any. If we adopt a figure of 7 $m^3$/year per capita because the Gihon is indeed a rich water source, and assume a population of 26,000 as suggested by Faust (2005) for Jerusalem of the seventh century B.C.E., we come up with a monthly consumption of about 43,000 $m^3$ ($13{,}000 \times 7/12 = 7{,}580$ $m^3$ + $13{,}000 \times 32/12 = 34{,}660$ $m^3$), which is about the same as the basic monthly discharge of the Gihon Spring (60 $m^3$/hour × 720 hours = 43,200 $m^3$). This means that there would have been no extra water left for irrigation during the dry season, making the above-discussed hydrogeological problem a very crucial factor that had to be addressed. To supply the growing demand for water, the Siloam Tunnel was constructed, this time at the spring's water level so that maximum water discharge could be transferred toward the Siloam Pool.

We know from Benami Amiel, Frumkin, and Grodek (2007) that the spring's response time to rainfall events is a matter of hours, a fact that attests to the cavernous character of the subsurface. Therefore, it is probable that the rising of the water near the spring would have caused water to start seeping near the Siloam Pool very shortly after water bursts, a phenomenon that would have been quite noticeable (Abells and Arbit 1995: 23, 24). Seeing this would have led to the realization that the watercourse ends were connected and that although the subsurface route was unknown, its length must be reasonably short. Digging a tunnel along this water route could then be implemented.

## HOW DID THE SILOAM TUNNEL'S WINDING ROUTE EVOLVE?

As local groundwater in the City of David area drains eastward, digging a tunnel in a north–south direction from the spring means digging along the equipotential line of the groundwater table (Avnimelech 1968) and having an almost horizontal tunnel floor. Indeed, the elevation difference between the ends of the Siloam Tunnel is 0.3 m or less (Wilson in Schick 1880: 238; Conder 1882; reaffirmed by Shiloh 1984), a remarkably gentle slope of 0.05%. Water flow below the water table and in the unsaturated zone above it takes place in a system of interconnected cavities, mainly dissolution (karstic) ones developing along subvertical fissures and in inclined bedding planes, conduits that could have guided the miners groping their way in the subsurface. Figure 3 displays such a flow system, demonstrating how changes in strike directions and passages from one bedding plane to another via fissures would result in a natural winding flow course when keeping the cutting surface horizontal. This would explain why the tunnel runs along a route which is far longer than the 318-m direct line connecting the spring and the Siloam Pool. Avnimelech (1968) claimed that the dipping bedding planes themselves were utilized as a guide for the miners. Fissures and cracks, some displaying dissolution features, have been noted as occurring in various places along the Siloam Tunnel (Gill 1996; Rosenberg 1998; Lancaster and Long 1999; Shimron et al. 2000; Reich and Shukron 2007), even though no continuous crevice along the full length of the tunnel has been traced. Not surprisingly, dissolution cavities in bedding planes have not been located. Those that functioned as water conduits and guided the miners are to be found at the tunnel floor, which is covered by a layer of 10-cm-thick plaster (Frumkin, Shimron, and Rosenbaum 2003), thus hiding the "evidence." Notably, not every bedding plane develops cavities, and therefore the failure to detect them on the tunnel's walls is not uncommon.

## HOW DID THE CEILING IN THE SOUTH SECTOR OF THE SILOAM TUNNEL COME TO BE EXCESSIVELY HIGH?

As mentioned above, the tunnel's height along the southernmost sector, along a 50-m stretch, exceeds 5 m and then decreases gradually along the next 20 m, down to about 2 m. Gill (1996) proposed that a karstic channel in the upper part of the tunnel required quarrying in a high sectional opening, whereas Reich and Shukron (2007) argued that an earlier tunnel was originally cut at a higher elevation as part of a plan to join the Siloam Channel, which runs at a higher elevation. Reich and Shukron's hypothesis, on top of additional theoretical deliberations, is supported by the existence of a recess, 0.55 m wide, found 15 m from the south entrance of the Siloam Tunnel on the east wall. Similar

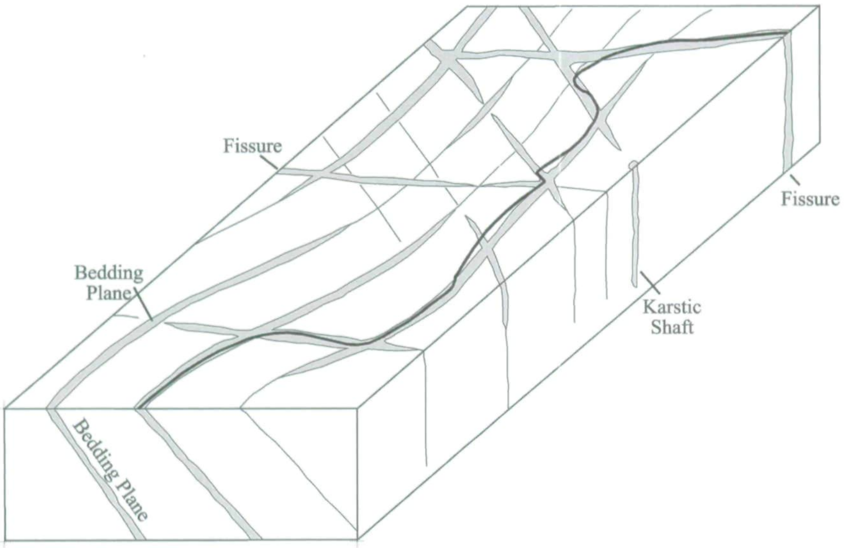

**Fig. 3.** Block diagram of hypothetical pattern of watercourses in fissures and in the dissolution cavities within inclined bedding planes below the groundwater table (top of block diagram). The precise route of the Siloam Tunnel (in black) is superimposed. For the sake of emphasis, the vertical scale is exaggerated.

deviations are well known along the tunnel, but here it exists only in the upper part of the wall, 2.8 m from the floor. Reich and Shukron assume that the plan was dropped, that tunneling was stopped and only at a later stage was it deepened to its present floor elevation. If this were the case, however, we would expect an abrupt transition from high ceiling to low ceiling, whereas the actual transition is gradual. Reich and Shukron (2007) do not address the gradual sloping ceiling issue. Yet, in another article (Reich and Shukron 2002b), they claim that the occurrence of cavities higher up in the section would have prevented the miners from meticulously cutting the ceiling. Bearing this argument in mind, then, why would the miners have spent precious time and exacting effort to create a gradual ceiling slope? It is more plausible that the existence of cavities, not necessarily interconnected and not necessarily large, were responsible for the need to hew an exceptionally high tunnel.

## HOW LONG DID IT TAKE TO COMPLETE THE ENTERPRISE AND WHO WAS BEHIND THE CONSTRUCTION?

As we have no direct information regarding the rate of cutting in the case of the Siloam Tunnel, we had two ways to derive an estimate: by extrapolating from records from other tunnels or by consulting experienced experts. The first option presents severe drawbacks: the rock types, bedding architecture, fracture intensity, and all other geotechnical properties must be identical or the resulting comparison will be completely misleading. We therefore chose to go with the second option, consulting three professional masons who are familiar with the local rock formations. The Siloam Tunnel was cut in very hard, massive dolostones, and according to the masons' assessments, the rate of cutting for an average sectional opening of ca. 1.4 $m^2$ would not exceed 0.35 m per 24-hour day. Accordingly, in the case of the Siloam Tunnel, where work was carried out simultaneously from both sides, the southern, longest sector, which is 300 m long, could have been completed in 900 24-hour working days. We accept the method of hewing suggested by Rosenberg (1998): working six 4-hour shifts (3 hours actual hewing plus 1 hour for changeover) per 24-hour day, six days per week, or about 300 working days per year. In each shift, only one worker at a time can do the actual hewing. Accordingly, we calculate: 300 m of tunnel/0.35 m per day = 857 days, which is about 3 years.

Extra time for planning, for hewing the easternmost sector of Tunnel VI (fig. 2) (the final 17-m-long connection with the spring), and for other preparatory measures should also be taken into account. According to Reich and Shukron (2000; 2004), the Siloam Tunnel starts from Tunnel IV (fig. 2) which bypasses the intermittently flooded spring area. Only by the end of the whole project was it possible to connect the tunnel directly with the spring through the west–east hewn eastern sector of Tunnel VI. It is conceivable that the 10-m-long Tunnel IV preceded the works from the southern end of the Siloam Tunnel because the intersection with the main crevice along which Tunnel VI would later be constructed had to have been ascertained in advance. In addition, there is no doubt that hardships such as poor ventilation and lighting problems must have, at times, slowed down the digging pace. All in all, it is reasonable to assume that the digging project took at least four years.

Before any work on the site could proceed, the water flow from the Siloam Channel toward the rock-cut water pool had to be blocked to avoid flooding Tunnel IV during its construction (Reich and Shukron 2000; 2004); thus the earlier waterwork had to be abandoned and replaced. Even though the access to Warren's Shaft was not opened before the eighth century B.C.E. (Reich and Shukron 2004), the fissure along which the natural shaft developed was apparently exposed, and it is highly probable that water could be seen at the base of the shaft. Moreover, the sound of intermittent gushing waters could have been heard, and the water level at the base of the shaft, only about 25 m away from the spring, presumably rose as well. Now that a replacement for the rock-cut water pool was crucial, the top of the shaft was exposed and water could be raised temporarily until the waterworks was completed. Faust (2003) argued that water was drawn from the shaft. We share this view, yet we stipulate that water was not supplied from the spring; Tunnel VI (fig. 2), leading to the spring itself, was opened, as already mentioned, only at the final stage of the waterwork construction (Reich and Shukron 2000; 2004). The water at the base of the shaft was there as the shaft reached below local groundwater level, and the short 6-m tunnel connection to the corner of Tunnel VIII (fig. 2) was apparently created to allow access and maintenance. Even though opening the Warren Shaft was an important preparatory measure, by itself it would not have taken long to carry out.

Our appraisal of the time required to complete the Siloam Tunnel is by far higher than that of Vincent (1911: 39) or Rosenberg (1998), who suggested 11 and 9 months, respectively, while it is in line with Robinson's (Robinson and Smith 1841: 502) description written after crossing the tunnel, having realized that "only a single person could have wrought in it at a time; and it must have been the labour of many years. . . ." In view of the time it took to complete the Siloam Tunnel project (as we estimate it), it seems that the tunnel of Channel II, which could be accomplished in a relatively short time—rather than the Siloam Tunnel—was the actual waterwork planned against a potential siege on Jerusalem by Sennacherib King of Assyria (2 Chron 32: 2–4) in the year 701 B.C.E.. This idea was first raised by Grossberg (2006), who argued that even 11 months was too long a period to consider the Siloam Tunnel as the one prepared against the siege. Moreover, in our view, it is this very waterwork, the tunnel of Channel II, that is referred to in 2 Chron 32: 30: "*And he Hezekiah stopped the exit of the upper watercourse of Gihon*" (i.e., the exit of the high-lying Channel II to the fields in the Kidron Valley) *"and he guided the waters straight down"* (via the newly constructed tunnel in continuation of Channel II) *"to the west side of the city of David."* The construction of the Siloam Tunnel thus must have taken place at a later period, most probably at the beginning of the seventh century B.C.E., during the reign of Manasseh (Hezekiah's son), King of Judah, a period known, according to Finkelstein (1994), Finkelstein and Silberman (2006: 151–77), and Faust (2008), for its political stability and economic prosperity.

In theory, Channel II could have been constructed following the fall of the northern kingdom, or even preceding it, and Hezekiah might have started to cut the Siloam Tunnel in, e.g., 705 B.C.E., four years before the siege. There is, however, a difficulty with this scenario: It completely disregards the biblical text, both Grossberg's and our interpretations of it. Furthermore, reading the biblical text concerning the preparations for the siege, one gets a sense of urgency, which is not compatible with a mega-project that is going to take at least four years to complete.

## CONCLUSIONS

Revisiting the ancient waterworks in the City of David has resulted in new insights into questions of why, how, and when the Siloam Tunnel was created. Estimating the water consumption in Jerusalem in the light of the Gihon Spring discharge, we found that by the end of the eight century B.C.E., Jerusalem faced a shortage of water. The situation became even more acute because water had to be raised in order to reach the floor of the higher-lying Channel II (channel and tunnel), through which most of the spring's water was diverted toward the Tyropoeon Valley at the time. This process could have operated effectively only during the wet season with its repeated gushes, and inevitably severe water losses ensued. It is this hydraulic failure that led to the construction of the Siloam Tunnel.

Gill (1996) and his predecessors answer the "how" question by suggesting a continuous preexisting natural conduit as the course for the Siloam Tunnel. To validate this hypothesis, at least theoretically, we had to find out what dictated this conduit's course. Taking into account the structural configuration at the site (fig. 3), we managed to demonstrate how changes in strike directions and passages from one bedding plane to another via fissures would result in a natural winding flow route along which the tunnel course runs.

The "when" question depends on the time it took to complete the enterprise. Consulting with professional masons, we arrived at a new assessment of at least three years of actual hewing of the tunnel, and one year for planning, for hewing the easternmost sector of Tunnel VI, the final connection with the spring, and for other preparatory measures, including the opening of the Warren Shaft. All in all, it is reasonable to assume that the hewing project took at least four years. In view of this assessment, it is implausible to consider the Siloam Tunnel project as the one urgently planned against a potential siege on Jerusalem by Sennacherib in the year 701 B.C.E. Instead, we suggest that Channel II was the one constructed to face the siege, as has already been proposed by Grossberg (2006). This view is also supported by our new interpretation of the relevant biblical text in 2 Chron 32:30. It follows, then, that the construction of the Siloam Tunnel must have taken place at a later period, most probably at the beginning of the seventh century B.C.E., during the reign of Manasseh.

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