Geology and Production History of the Moonlight Uranium-Vanadium Mine, Navajo County, Arizona

By
William L. Chenoweth
Consulting Geologist, Grand Junction, Colorado

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Arizona Geological Survey
416 W. Congress, Suite #100, Tucson, Arizona 85701

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This report is preliminary and has not been edited or reviewed for conformity with Arizona Geological Survey standards.
INTRODUCTION

During the mid-1950s exploration drilling located several large uranium ore bodies in buried channels, in the Oljeto syncline area of the Monument Valley, Navajo County, Arizona. The channels occupy the basal portion of the Shinarump Member of the Triassic Chinle Formation. The Moonlight Mine was the largest of these deposits and was the second largest deposit in the entire Monument Valley area. The deposit was located on a Navajo Tribal Mining Permit, which was issued in 1953, at a time when mining and exploration were just commencing in this part of Monument Valley. The Moonlight was originally an underground mine but was converted to an open pit operation once the size of the deposit was established.

As the result of a lawsuit involving the Moonlight Mine, considerable additional information was located including a map of the underground workings. This report incorporates the new information and supersedes a former report CR-95-D.

LOCATION AND LAND STATUS

The Moonlight Mine was located approximately five miles south of Oljeto, Utah in Navajo County, Arizona, within the Navajo Indian Reservation (Figure 1). The open pit is shown on the Boot Mesa 7.5 minutes topographic map [U.S. Geological Survey, 1988] at latitude 36°57'48" north and longitude 100°17'00" west. The mine site was reached by a series of graded roads that headed south from Oljeto. In 1994, the Navajo Abandoned Mine Lands Reclamation Program back filled the pit.

Mining permits and leases within the Navajo Reservation were issued by the Navajo Tribal Council and approved by the Bureau of Indian Affairs (BIA), U.S. Department of Interior. Only individual Navajos could obtain mining permits. Permit holders could assign the mining rights to another individual or a company; like the permits these assignments had to be approved by the Tribal Council and the BIA. Leases could be issued directly by the BIA. Permits were issued for a 2-year period and could be renewed for an additional 2 years. Leases were issued for periods up to 10 years. Any one company or individual could hold no more than 960 acres of tribal land. Both the permittee and the tribe received royalties from ore production. Based on the mine value of the ore, the tribe received between 10% and 20% royalties and
the permittee between 2% and 5% royalties. In addition to mining permits, the tribe issued drilling and exploration permits. These permits were good for 120 days and were not renewable.

**GEOLOGICAL SETTING**

The Moonlight ore deposit was one of several uranium ore deposits that were located by “blind” drilling in the El Capitan Flat area of Monument Valley in 1955-1956. The Flat is a large, sand dune-covered area on the eastern side of the Oljeto syncline, which is between the Organ Rock anticline to the west and the crest of the Monument Uplift to the east. Underlying the dune sand in the mine area is the Upper Triassic Chinle Formation. Rocks of this formation dip approximately 2 degrees to the west-southwest into the syncline [Witkind and Thaden, 1963].

The ore bodies at the Moonlight Mine were formed in a channel deposit in the basal portion of the Shinarump Member of the Chinle Formation. The channel, scoured into the underlying Moenkopi Formation of Lower Triassic age, was filled with gray, medium-to-coarse-grained sandstone and conglomerate. Carbonaceous plant materials, including fossil logs were abundant in the channel sediments. The channel at the mine was 300 feet wide and was scoured 50 to 75 feet into the underlying siltstone of the Moenkopi Formation. Locally, the scouring reached the Permian DeChelly Sandstone, which underlies the Moenkopi Formation. Studies of the Shinarump channels in the Monument Valley area by Young and others [1964] indicate that the Moonlight Mine was located where a northwest-trending channel, which contains the Monument No. 1 - Mitten No. 2 deposits, makes a sharp bend to the southwest (Figure 2).

When mining was completed at the Moonlight the oval-shaped pit was 750 feet long, 525 feet wide and 145 feet deep. The long axis of the pit trended N 308E, the trend of the channel. Ore bodies at the Moonlight averaged 14.5 feet in thickness. Ore thicknesses up to 30 feet were found on the flanks of the channel [John Borkert, personal communication, 1994]. Young [1964, p. 867] noted that high-grade vanadium ore occurred below the uranium in the siltstones of the Moenkopi Formation. Ore in the Moenkopi extended downward as much as 15 feet below the unconformity at the base of the Chinle Formation. Kenneth G. Hatfield of Kerr-McGee Oil Industries, Inc. examined the Moonlight Mine on November 14, 1961. Figure 3 is his cross-section of the lower part of the pit showing the location of ore bodies in the Shinarump channel.
The minerals at the Moonlight were unoxidized due to protection by the overlying siltstones and mudstones of the Monitor Butte Member of the Chinle Formation. As mining commenced in the south ore body, water began seeping into the mine due to a perched water table in the Shinarump. This necessitated a sump being constructed and a pump being installed at the foot of the decline. The flow of water decreased and water was not a problem in the underground mine [John Borkert, personal communication, 1994]. When the author examined the open pit in the summer of 1967 the pit was dry. However, Longsworth [1994, p. 20] noted four feet of water in the pit in October, 1991.

Samples collected by AEC geologists from the underground mine were examined by Alice S. Corey, an AEC petrologist. Uraninite was the only uranium mineral identified, and occurred with various copper minerals, galena, montroseite and calcite replacing fossil wood and as cement in the sandstone and conglomerate. The copper minerals included bornite, chalcocite, chalcopyrite and covellite [Corey, 1956]. Young [1964, p.870] recorded that the molybdenum minerals, ilsemannite and jordisite were conspicuous at the Moonlight.

Corey [1956] made a paragenetic study of the minerals, which is repeated here:

"The wood deposited in the original sediments was partially metamorphosed. With the introduction of ore-bearing solutions, many of the cell centers were filled with bornite. In many places the bornite replaced all of the fossil wood and filled cracks forming large masses of bornite. Although most of the bornite remaining is in the fossil wood, bornite also cements sand grains probably having replaced early fine-grained calcite cement. Galena replaced bornite in some places and was replaced by bornite in others. Galena was observed only in the sandstone. Chalcopyrite veined and replaced bornite in wood and in sandstone, with a large proportion presently occurring in the sandstone. Chalcopyrite replaced massive bornite in an irregular cuniform texture. In the sandstone bornite has nearly all been replaced by chalcopyrite or galena. Chalcocite is a later ore mineral than either bornite or chalcopyrite. Chalcocite replaced bornite and chalcopyrite in wood and sandstone and also filled cell centers in wood, whether by replacement of bornite or by filling voids. Deposition of uraninite was later than either chalcopyrite or bornite but overlapped that of chalcocite. In the sandstone uraninite is in some places the
only cement. In others it occurs with galena and/or bornite and/or chalcopyrite. Needles of montroseite selectively replaced uraninite and occasionally chalcopyrite. Rare blebs of covellite were observed in the massive bornite in woody sections. The covellite appears to be later than the bornite and chalcopyrite, but its relations other ore minerals was not seen. In the sandstone organic materials appear to have been mobile enough to fill fractures and penetrate along grain boundaries.

There is a hint of zoning present, with bornite and chalcocite being concentrated in woody portions and decreasing with increasing distance from the wood, while chalcopyrite and uraninite increased in the amount in the sandstone away from the wood. Montroseite was not observed in woody sections”.

There is no information available regarding the overall copper content of the Moonlight ore. John Borkert [personal communication, 1994] recalled that the Moonlight Mine contained less copper than the other deposits mine by Industrial Uranium Company in the Oljeto syncline, especially the Starlight and the Sunlight. The mill at Mexican Hat, Utah paid for sulfide copper in uranium ores in excess of one percent. It is doubtful payments were made for any Moonlight ore [Borkert, personal communication, 1994].

In October 1956, a 333-pound sample of Moonlight ore was sent to the AEC’s Raw Materials Development Laboratory at Winchester, Massachusetts, operated by the National Lead Company, Inc. This sample contained 0.375 percent $U_3O_8$, 0.53 percent $V_2O_5$ and 0.66 percent Cu [Porter and others, 1958].

**EXPLORATION AND PRODUCTION HISTORY**

Early in 1953, Seth T. Bigman staked the Moonlight Nos. 1 and 2 claims in the El Capitan Flat area of Navajo County, approximately five miles northwest of Monument No. 1 - Mitten No. 2 uranium mines (Figure 2). The land was acquired in anticipation of future exploration drilling in the area of a projected trend of the Monument No. 1 - Mitten No. 2 channel. Navajo Tribal Mining Permit (MP) No. 73 was approved to Mr. Bigman on February 19, 1953. It included the 320 acres No. 1 claim and the contiguous 280 acres No. 2 claim.
In 1954, Industrial Uranium Company of Salt Lake City, Utah obtained a drilling permit for the entire 600 acres. This drilling was successful as a large ore body was located in the southwest corner of the Moonlight 1 claim, which extended on to the Moonlight No. 2 claim. Industrial applied for the assignment of the mining rights for only 40.8 acres of the mining permit. This assignment was approved on November 3, 1955.

Industrial drove an 8 x 10 foot, 430 foot-long decline to the ore body. Track haulage in the ore zone was used with a modified room and pillar mining method. A 1.5-ton, 15 horsepower electric hoist was used to pull ore cars up the 20 degree decline [U.S. Atomic Energy Commission, 1959]. An initial shipment of 44 tons averaging 0.17 percent $U_3O_8$ was made to the AEC ore-buying station at Monticello, Utah on March 1, 1956. During 1956 a total of 10,426.12 tons of ore averaging 0.34 percent $U_3O_8$ and 0.38 percent $V_2O_5$ were shipped to Monticello (Tables 1 and 2). At Monticello, the AEC paid for the vanadium content of the ore as well as for the uranium.

On June 26, 1957, the 40.8 acres of the Moonlight mining permit and 67.2 acres of Seth T. Bigman’s Navajo Tribal Mining Permit 354, the Starlight Nos. 1 and 2 were converted to Lease No. 14-120-603-2289 [Chenoweth, 1997]. This lease was for a period of ten years.

During 1957, underground mining continued with a total of 39,736.45 tons of ore averaging 0.33 percent $U_3O_8$ and 0.54 percent $V_2O_5$ shipped to Monticello (Tables 1 and 2). The Arizona mine inspector recorded that during 1957 between 25 and 63 men were employed underground at the Moonlight Mine (Table 3).

During 1958, shipments continued to Monticello with some 1,426.31 tons shipped to the newly opened mill at Mexican Hat, Utah, operated by Texas Zinc Minerals Corporation. The distance from the mine to Mexican Hat was 30 miles compared to 67 miles to Monticello. Mexican Hat did not pay for, or recover vanadium. In 1958 the mine inspector noted that 27 men were underground and 11 men were on the surface (Table 3).

Due to the excellent continuity of the ore, which averaged 14.5 feet thick, Industrial decided to open pit the remaining ore bodies. During the last quarter of 1958, the underground mining was suspended. Figure 4 is a map of the underground workings just prior to the closing of the mine. Late in 1958 the removal of the overburden began with Wells Cargo, Inc. of Reno, Nevada as the contractor. Power shovels and diesel trucks were for the stripping. Much of the overburden sandstone and shale of the Monitor Butte Member of the Chinle Formation had to be blasted with dynamite in order to be removed.
Total production during 1958 was 27,877.68 tons, averaging 0.34 percent U₃O₈ (Table 1). Industrial reported to the AEC that as of November 24, 1958, the Moonlight Mine had a remaining reserves of 136,000 tons of ore that averaged 0.26 percent U₃O₈ and 0.50 percent V₂O₅.

On January 15, 1959, production began from the open pit with the ore being shipped to Mexican Hat. In mid-1959, Rare Metals Corporation of American, which operated a mill at Tuba City, Arizona, signed a contract with Industrial to purchase 20,000 tons of ore over the next 12 months. Production in 1959 reached an all time annual high when 73,730.63 tons averaging 0.23 percent U₃O₈ were shipped (Table 1). In this same year the mine inspector recorded that 14 men were employed in the open pit (Table 3).

Operations in the open pit mine were turned over to a contractor, North Elk Mining Co. of Blanding Utah, in 1960. During that year production continued to be shipped to both Mexican Hat and Tuba City, but declined to 34,018.47 tons averaging 0.23 percent U₃O₈, a 54 percent drop from 1959 (Table 1).

During 1961 production continued to decline when 17,824.60 tons averaging 0.20 percent U₃O₈ were shipped to Mexican Hat (Table 1). This was a drop of 48 percent over 1960.

In 1962, some 1,717.10 tons of high vanadium ore (1.49 percent V₂O₅) were shipped to Monticello, before the ore-buying station closed on March 31, 1962 (Table 2). Total production in 1962 was 9,866.95 tons averaging 0.30 percent U₃O₈ (Table 1), a decline of 44 percent from 1961. The mine inspector recorded that North Elk Mining Co. had only 2 to 3 men employed at the mine in 1962 (Table 3).

On July 31, 1963, the Atlas Corporation acquired Texas Zinc Minerals Corporation, including the Mexican Hat mill. Texas Zinc’s AEC contract was merged into the Atlas Minerals contract at their mill at Moab, Utah. Atlas continued to operate the Mexican Hat mill through a subsidiary, A-Z Minerals [Albrethsen and McGinley, 1982].

The only ore shipped from the Moonlight Mine in 1963 was some high vanadium ore, which was delivered to the uranium-vanadium mill at Grand Junction, Colorado operated by Climax Uranium Company. This shipment consisted of 148.10 tons averaging 0.39 percent U₃O₈ and 1.37 percent V₂O₅ (Tables 1 and 2). The high -grade vanadium ore produced in 1962 and 1963 no doubt came from the ore bodies in the Moenkopi Formation.

With most of the higher grade ore exposed in the open pit depleted by 1963, clean up mining commenced in 1964. During that year shipments resumed to the Mexican Hat mill now operated by A-Z Minerals. A total of 2,520.17 tons with an average grade of 0.18 percent U₃O₈ were produced during 1964
(Table 1). The mine inspector recorded four men employed by North Elk Mining in the Moonlight pit during 1964 (Table 3).

At the end of February 1965, A-Z Minerals closed the Mexican Hat mill [Albrethsen and McGinley, 1982]. Since Atlas Minerals had acquired the Moonlight’s ore purchase contract with the Mexican Hat mill, shipments now had to be sent to the Atlas mill at Moab, Utah. During 1965 a total of 3,139.84 tons averaging 0.18 percent U$_3$O$_8$ were shipped from the Moonlight Mine (Table 1).

As the ore bodies in the floor of the open pit were mined out, a contract miner, U.A. Small mined ore outside of the pit via adits from the pit walls. During 1966 the mine inspector noted that the only employees at the Moonlight were two men working underground (Table 3). In 1966, the final shipments from the mine totaled 3,947.76 tons with an average grade of 0.13 percent. All of the ore was shipped to Moab (Table 1).

SUMMARY

During the 11 years the Moonlight Mine was operating a total of 223,236.77 tons of ore averaging 0.26 percent U$_3$O$_8$ and containing 1,177,501.29 pounds U$_3$O$_8$ were produced. This production ranks the Moonlight the second largest uranium mine in the Monument Valley area. The largest mine was the Monument No. 2 in Apache County, Arizona (Figure 1). This mine, the largest in Arizona during the AEC program, produced 773,132 tons averaging 0.34 percent and containing 5,276,093 pounds U$_3$O$_8$ [Gregg and Eversen, 1989].

All of the uranium concentrate produced from the Moonlight ore was sold to the remainder was sold by the AEC to vanadium companies [Albrethsen and McGinley, 1982]. AEC. The vanadium recovered at the Climax mill at Grand Junction, Colorado was sold to the steel industry. Ores purchased by the AEC at Monticello, Utah were processed at the adjacent AEC owned mill. Vanadium was recovered only during the September 1949 - March 1956 period [Albrethsen and McGinley, 1982]. The majority of the vanadium recovered at the Monticello mill was transferred to the General Service Administration. The remainder was sold by the AEC to vanadium companies [Albrethsen and McGinley, 1982].

ACKNOWLEDGMENTS. John Borkert, a former mining engineer for Industrial Uranium Company in Monument Valley, supplied many details of mining operations. Nyal J. Niemuth of the Arizona
Department of Mines and Mineral Resources kindly made the annual reports of the Arizona mine inspector available to the author. Research by Tad Woods, of Meyer, Hendricks and Bivens, located much of the new material presented in this report. Stephen M. Richard of the Arizona Geological Survey reviewed and improved the manuscript. Tom McGarvin located Corey's petrographic report in the Arizona Survey's files.

REFERENCES


MOONLIGHT MINE CHRONOLOGY

February 19, 1953 Seth T. Bigman was issued Mining Permit No. 73 for 600 acres named the Moonlight Numbers 1 and 2 claims.

Summer 1954 Industrial Uranium Company took out a drilling permit on the Moonlight claims and discovered a large orebody.

November 3, 1955 Industrial was assigned the mining rights to 40.8 acres of Mining Permit No. 73.

Winter 1955-1956 Industrial drove a 430 foot long decline into the south orebody.

March 1, 1956 Initial shipments to the AEC ore-buying station at Monticello, Utah. Room and pillar mining with track haulage in ore zone.

June 26, 1957 Converted the assignment of the mining permit to Lease No. 14-120-603-2289. Lease was for 10 years.

1958 Mining extended into north orebody. Decided to open pit remaining orebodies.

October 1958 Ceased all underground mining. Pit was stripped by Wells Cargo, Inc. using shovels and trucks.

January 15, 1959 Initial production from the open pit. Production in 1959 shipped to Mexican Hat and Tuba City mills.

1960 Open pit mining turned over to a contractor, North Elk Mining Co. Production declined by 54% over previous year.

1961 Production declined by 48% over previous year.

1962 Production declined by 44% over previous year. Some ore shipped to Monticello before the ore-buying station closed on March 31, 1962.
1963
Only 148 tons shipped during the year, all to Grand Junction mill.
1964
Shipments resumed to Mexican Hat.
1965
Mexican Hat mill closed in February, shipments continued to Moab mill.
1966
Underground mining off pit walls by U.A. Small, a contractor. Final shipments made to Moab. Second largest uranium ore deposit in the Monument Valley area.
Table 1. Uranium ore production, Moonlight Mine, Navajo County, Arizona

<table>
<thead>
<tr>
<th>YEAR</th>
<th>TONS OF ORE</th>
<th>POUNDS U₃O₈</th>
<th>% U₃O₈</th>
<th>DELIVERY POINT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1956</td>
<td>10,426.12</td>
<td>70,717.65</td>
<td>0.34</td>
<td>Monticello</td>
</tr>
<tr>
<td>1957</td>
<td>39,736.45</td>
<td>259,243.08</td>
<td>0.33</td>
<td>Monticello</td>
</tr>
<tr>
<td>1958</td>
<td>27,877.68</td>
<td>189,434.84</td>
<td>0.34</td>
<td>Monticello, Mexican Hat</td>
</tr>
<tr>
<td>1959</td>
<td>73,730.63</td>
<td>338,025.76</td>
<td>0.23</td>
<td>Mexican Hat, Tuba City</td>
</tr>
<tr>
<td>1960</td>
<td>34,018.47</td>
<td>158,994.24</td>
<td>0.23</td>
<td>Mexican Hat, Tuba City</td>
</tr>
<tr>
<td>1961</td>
<td>17,824.60</td>
<td>69,684.70</td>
<td>0.20</td>
<td>Mexican Hat</td>
</tr>
<tr>
<td>1962</td>
<td>9,866.10</td>
<td>59,646.10</td>
<td>0.30</td>
<td>Mexican Hat, Monticello</td>
</tr>
<tr>
<td>1963</td>
<td>148.10</td>
<td>1,155.28</td>
<td>0.39</td>
<td>Grand Junction</td>
</tr>
<tr>
<td>1964</td>
<td>2,520.17</td>
<td>9,253.34</td>
<td>0.18</td>
<td>Mexican Hat</td>
</tr>
<tr>
<td>1965</td>
<td>3,139.84</td>
<td>11,027.29</td>
<td>0.18</td>
<td>Mexican Hat, Moab</td>
</tr>
<tr>
<td>1966</td>
<td>3,947.76</td>
<td>10,318.94</td>
<td>0.13</td>
<td>Moab</td>
</tr>
<tr>
<td>MINE TOTAL</td>
<td>223,236.77</td>
<td>1,177,501.29</td>
<td>0.26</td>
<td></td>
</tr>
</tbody>
</table>


Table 2. Vanadium content of uranium ore shipments, Moonlight Mine, Navajo County, Arizona

<table>
<thead>
<tr>
<th>YEAR</th>
<th>TONS OF ORE</th>
<th>POUNDS V₂O₅</th>
<th>% V₂O₅</th>
<th>DELIVERY POINT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1956</td>
<td>10,426.12</td>
<td>78,992.00</td>
<td>0.38</td>
<td>Monticello</td>
</tr>
<tr>
<td>1957</td>
<td>39,736.45</td>
<td>425,608.03</td>
<td>0.54</td>
<td>Monticello</td>
</tr>
<tr>
<td>1958</td>
<td>26,451.37</td>
<td>380,899.71</td>
<td>0.72</td>
<td>Monticello</td>
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<tr>
<td>1962</td>
<td>1,717.10</td>
<td>51,169.54</td>
<td>1.49</td>
<td>Monticello</td>
</tr>
<tr>
<td>1963</td>
<td>148.10</td>
<td>4,056.01</td>
<td>1.37</td>
<td>Grand Junction</td>
</tr>
<tr>
<td>MINE TOTAL</td>
<td>78,479.14</td>
<td>940,725.29</td>
<td>0.60</td>
<td></td>
</tr>
</tbody>
</table>

Source: Unpublished ore production records, U.S. Atomic Energy Commission, Grand Junction, Colorado Office. No shipments where vanadium was recovered were made in 1959-61 or 1964-66.
Table 3. Employment at the Moonlight Mine, from the annual reports of the Arizona Mine Inspector.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>NUMBER OF INSPECTIONS</th>
<th>MEN ON SURFACE</th>
<th>MEN UNDERGROUND</th>
</tr>
</thead>
<tbody>
<tr>
<td>1955</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1956</td>
<td>1</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>1957</td>
<td>4</td>
<td>13-23</td>
<td>25-62</td>
</tr>
<tr>
<td>1958</td>
<td>1</td>
<td>11</td>
<td>27</td>
</tr>
<tr>
<td>1959</td>
<td>1</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>1960</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1961</td>
<td>5</td>
<td>3-4</td>
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<tr>
<td>1962</td>
<td>3</td>
<td>2-3</td>
<td>0</td>
</tr>
<tr>
<td>1963</td>
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</tr>
<tr>
<td>1966</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>1967</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
FIGURES

Figure 1. Index map of Monument Valley, Arizona-Utah showing the location of the Moonlight uranium-vanadium mine.

Figure 2. Map of the El Capitan Wash area, Navajo County, Arizona, showing Shinarump channels and uranium deposits. After Young and others [1964].

Figure 3. Generalized cross-section of the lower part of the Moonlight open pit looking north. Symbols: Trc. Shinarump Member, Chinle Formation; Trm, Moenkopi Formation upper member; Trmh, Hoskinnini Member, Moenkopi Formation; Pcd, DeChelly Sandstone. Geology by K.G. Hatfield, 1961.

Figure 4: Plan map of the underground workings of the Moonlight Mine prior to stripping, November 1958.
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Figure 2. Map of the El Capitan Wash area, Navajo County, Arizona, showing Shinarump channels and uranium deposits. After Young and others [1964].
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