Department of Primary Industries

Opal mining on the alluvial soils at Lightning Ridge

Report on a visit to Lightning Ridge conducted on 29 November 2012

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Soil Issues: Opal mining on the alluvial soils at Lightning Ridge

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Contents

Summary

A site visit to mine sites on floodplain soils north west of Lightning Ridge on 29 November 2012 determined a number of problems:

- Catastrophic failure of mines – where inundation had triggered a total mine collapse and caused instability in the surrounding soil. The erosion processes are expected to continue for some time if left unremediated.
- Collapse and instability of rehabilitated mine sites – where soil had been piled over these sites and the soil had subsequently collapsed into the shaft.
- Collapse of nine inch exploration holes. These exploration holes are generally covered as best they can however result in collapse through processes similar to that of the collapse of the rehabilitated mine sites.
- Disintegration of the inside of the mine shaft. As the soil dries out, progressive layers of soil crack from the sides of the mine shaft.
- Reported instability of mining activity on floodplain soils. Cracks and slickensides on Vertosols mean that these soils probably provide no structural stability.

These problems resulted in a range of concerns by the landholders relating to stock welfare, safety and damage to the environment.

The cracking clays on the floodplains have unique properties which make them highly erosive and unstable. The collapse of mines and slumping as a result of erosion and instability associated with cracking clays were witnessed during the study. The cracking clays erosion potential and instability raises concerns over the ability to bear loads under traditional opal prospecting techniques and technology (which is a concern when mining underneath them).

While there appeared to be a number of measures that miners had taken to stabilize the mineshafts, it is unclear whether these measures would be enough in a period of extended inundation. With respect to the instability of the cracking clays as a load bearing soil under which can be safely mined, this is beyond the knowledge of the author and consulting with an engineer experienced in working with cracking clays is recommended.

There does not appear to be any immediate solution to rehabilitating expired mines on these cracking clays and a guideline for doing these needs to be developed.

List of Figures

Introduction

Following the drafting of policies for the new opal prospecting boundaries (OPB) and black soil claim security, concerns were raised regarding environmental and safety issues of prospecting and mining for opal on the heavy clay floodplains around Lightning Ridge. Cases of mines sited on the floodplains failing have already been identified and a number of concerns had been raised:

- Erosion and collapse of working mine sites following flooding and inundation, being a danger to both miners and landowners.
- Slumping of rehabilitated mine sites, causing danger to landholders and livestock.
- Environmental issues associated with complex hydrology at the boundary of the floodplain soils with the 'ridge soils'.

A site visit was organized to inspect the effects of mining on the floodplain. The visit took place on 29 November 2012. Steve Clipperton (Regional Environmental Officer – Department of Resources and Energy), John Friend (Technical Leader, Agricultural Land Management – Department of Primary Industries) and Mick Babic (Mine Safety Officer – Department of Resources and Energy) inspected sites with landowners Ross Slack-Smith, Doug Lehman and Rick Hall. The sites inspected were on the Knightlife and Kitty Hawk areas, found in the Coocoran opal fields north west of Lightning Ridge. Both Knightlife and Kitty Hawk are on the floodplain of the Narran River.

Genesis of Lightning Ridge floodplain soils

The area described lies within the Narran River Floodplain system and the Lower Balonne Floodplain system. The landscape above the floodplain soils is Cretaceous (145-66 million years old) sandstone and quartzite sediments capped in some places with more recent silcrete (Thoms et al. 2002). The soils on the floodplains of Lightning Ridge are predominantly grey cracking clays, known as Vertosols in the Australian Soil Classification (Isbell 2002). Parent material is probably weathered siltstone or mudstone (McKenzie et al. 2004). These soils are part of a large distributory floodplain system, originating in St George and fanning out in the river systems originating from the Balonne. While the extensive cracking clays on the Namoi floodplain which extends from east of Narrabri to Walgett probably originated from parent material in the Nandewar Range, originating from several volcanos arising 13-14 million years ago (Ward 1999), the Vertosols in the Lightning Ridge area are considerably less studied but probably originated from parent material in southern Queensland, possibly windblown from central and south east Queensland and deposited in alluvial events (Thoms et al. 2002).

While clays are classified according to their particle size (clay particles are defined as being less than 2 microns or 0.002 millimetres), clays are not simply very small sand and silt particles. Clay particles originate through the chemical weathering of parent material in a range of ways, resulting in the reformation of very small colloids which then attach to each other in multiple layers. The type of clay produced depends on the primary rock material, environmental conditions in the soil and the intensity of leaching (McKenzie et al. 2004). While this is a very complex process, the resulting clays can show very different properties.

If a single tetrahedral and octahedral layer joins together, this is termed a 1:1 clay particle. If two tetrahedral sheets sandwich an octahedral sheet between them, this is termed a 2:1 clay particle. These individual clay mineral particles attach to each other if the clay mineral particles are 1:1 minerals and are attached to each other by cations if the clay particles are 2:1 particles (Anderson et al. 1999). Hundreds of these mineral particles can attach to each other forming a complex structure. Soils with a high proportion of 1:1 clays (such as kaolinite) tend to harden without shrinking at all. This makes them very hard to manage for agriculture but quite sought after for clay firing purposes such as brick making and pottery. Clays with a 2:1 structure (such as montmorillonite) allow water to attach to the ions in between the clay layers. This causes the clays to swell when they are wet and to shrink when they are dry, which is the reason these are termed cracking clays. These cracking clays are a feature of the floodplain soil in the study area.

For the purpose of this report, the Vertosols on the floodplains will be referred to as ‘floodplain soils’ while the other soils on what is colloquially known as the ridges and which have been traditionally mined, will be referred to as ‘ridge soils’.

A feature of the intersection of the ridge soils with the alluvial soils is that the ridge soils sometimes overlay the alluvial soils in a thin layer due to erosion over the ages. This makes picking the boundary between the two soil types a little more difficult. The boundary however can usually be determined through vegetation changes, with trees growing on the ridge soils being different to trees growing on the floodplain soils.

Properties of Lightning Ridge floodplain soils

Whilst there is a plethora of Vertosols which have been examined in the Namoi floodplain, since the origins of the cracking clays are different, it is not relevant to associate the soil properties of these soils with those on which opal mines are being proposed. Examination of the Soil and Land Information Systems (SALIS) database found seven grey Vertosols in the general area north west of Lightning Ridge. The properties of these soils have been summarized in Table 1. While each soil sample was allocated depths which were suitable for its testing, it should be noted that the depths are different for each location. Therefore it is not possible to compare between sites, just to make some general observations.

As can be seen from Table 1, the Vertosols are characterised by high clay contents with most of the remainder being composed of silts and fine sand. There was only a small proportion of coarse sand present and no gravel was found in any of the samples at any depths.

None of the soils were acidic, with pH (water) values all above 7, indicating neutral to alkaline soils.

While electrical conductivity in surface layers showed low salinity levels, there were several instances of moderate and high salinity in the lower layers. These high EC values may indicate the presence of harmful salts but may also indicate the presence of gypsum.

All locations showed relatively high cation exchange capacities, which is to be expected in heavy cracking clays.

During heavy storms and/or inundation, water flows freely down and along the cracks until the cracks swell and then close up. The cracks are termed temporary macropores since they are large cracks which are not present when the soil has been wet up. Permanent macropores are formed in these soils if roots and earthworms force their way through the soil. Permanent macropores do not close when the soil wets and swells and therefore can be the source of the majority of the infiltration and water flow once the cracks have closed. Another source of permanent macropores are small erosion events where soil is washed along the cracks, causing varying sizes of ‘pipelines’. These often manifest themselves on the surface as what are colloquially known as ‘crabholes’ – an unevenness in the surface which can vary from a small depression to a larger hole which can cause injury to livestock if trodden in.

Infiltration rates for Vertosols are often high when they are dry due to preferential flowpaths down existing cracks. Once these cracks are closed however, the infiltration rates can be very slow. This can be exacerbated by dispersive subsoils (with a high ESP) which can reduce infiltration rates to almost zero. The clay particles in dispersive subsoils break apart, closing many of the smaller permanent macropores causing the reduced infiltration.

Exposure of the highly dispersive subsoils can result in severe erosion. Intersecting these soils with a void can result in both the subsoils being exposed and raises the risk of water carrying soil through the cracks. This process can cause a permanent macropore to form which can then act as a ‘plughole’ and cause extensive erosion.

At depth, these Vertosols form plates which move against each other called slickensides. These are shear plates which enable the movement of this soil at depth. However, these shear plates could also be seen as a weakness in mined soils, providing no structural stability in the Vertosols for the soil being mined below.

Table 1: Summary of properties from seven Vertosols obtained from the SALIS database.

SALIS code	**LR067**	**GD042**	**LR922**	**LR004**	**LR071**	**LR064**	**LR044**
Easting	582732	547501	552993	567811	566675	556294	577797
Northing	6781342	6758386	6750873	6761487	6774192	6755098	6764865
Depth (m)	**0.0-0.2**	**0.0-0.07**	**0.0-0.15**	**0.0-0.05**	**0.0-0.05**	**0.0-0.06**	**0.0-0.04**
Clay	55	45	48	51	48	59	56
Silt	16	12	14	27	39	18	15
Fine Sand	28	36	36	20	13	21	24
Coarse Sand	2	7	3	1	1	1	5
Gravel	0	0	0	0	0	0	0
EC 1:5	0.09	0.13	0.17	0.11	0.11	0.13	0.14
pH Water	7.8	7.7	8.4	7.6	8.1	7.6	7.9
pH $CaCl_2$	7.1	7.2	7.7	7.0	7.5	7.1	7.5
CEC	31.4	27.7	26.9	32.8	42.8	36.9	31.7
Ca	18.1	14.4	22.5	19.1	29.0	19.8	21.9
Mg	6.8	8.2	5.7	8.7	6.1	9.5	7.0
K	0.9	0.8	0.9	2.9	1.6	1.9	1.6
Na	1.4	1.9	1.2	0.4	0.5	1.8	0.5
ESP	4.46	6.86	4.46	1.22	1.17	4.88	1.58
Depth (m)	**0.2-0.9**	**0.07-0.58**	**0.15-0.50**	**0.05-0.74**	**0.05-0.8**	**0.06-0.8**	**0.04-1.2**
Clay	52	56	53	61	61	31	61
Silt	24	13	11	23	26	11	9
Fine Sand	23	25	33	16	12	56	25
Coarse Sand	1	6	3	1	1	2	6
Gravel	0	0	0	0	0	0	0
EC 1:5	2.61	0.81	0.39	0.27	0.28	0.6	0.2
pH Water	7.4	7.7	8.7	8.4	8.6	7.9	8.6
pH $CaCl_2$	7.1	7.0	7.9	7.5	7.7	7.1	7.7
CEC	54.2	30.8	28.5	33.0	40.3	38.9	30.5
Ca	39.7	15.3	17.8	20.5	23.9	22.4	18.0
Mg	12.3	8.7	7.8	8.4	6.5	9.5	7.4
K	0.7	0.5	0.8	1.2	1.4	1.2	1.1
Na	6.8	4.4	3.0	3.0	3.0	4.3	3.2
ESP	12.55	14.29	10.53	9.09	7.44	11.05	10.49
Depth (m)	**0.9-1.2**	**0.58-0.9**	**0.5-1.0**	**0.74-1.16**	**0.8-1.35**	**0.8-1.4**	**1.2-1.5**
Clay	59	61	57	61	66	55	63
Silt	18	14	11	23	26	21	11
Fine Sand	22	21	29	16	7	23	21
Coarse Sand	1	4	2	1	1	1	5
Gravel	0	0	0	0	0	0	0
EC 1:5	1.04	2.14	0.66	0.69	0.71	1.47	0.43
pH Water	7.6	7.7	8.6	8.2	8.5	7.8	8.6
pH $CaCl_2$	7.2	7.4	8.0	7.3	7.7	7.0	7.7
CEC	32.8	32.2	31.4	33.3	40.0	39.2	30.9
Ca	18.2	18.6	16.4	19.5	21.8	21.9	15.8
Mg	10.3	11.0	9.3	9.7	7.4	10.7	8.3
K	0.8	0.7	1.0	1.4	1.5	1.2	1.2
Na	3.6	5.3	4.9	4.7	5.3	5.9	5.5
ESP	10.98	16.46	15.61	14.11	13.25	15.05	17.80

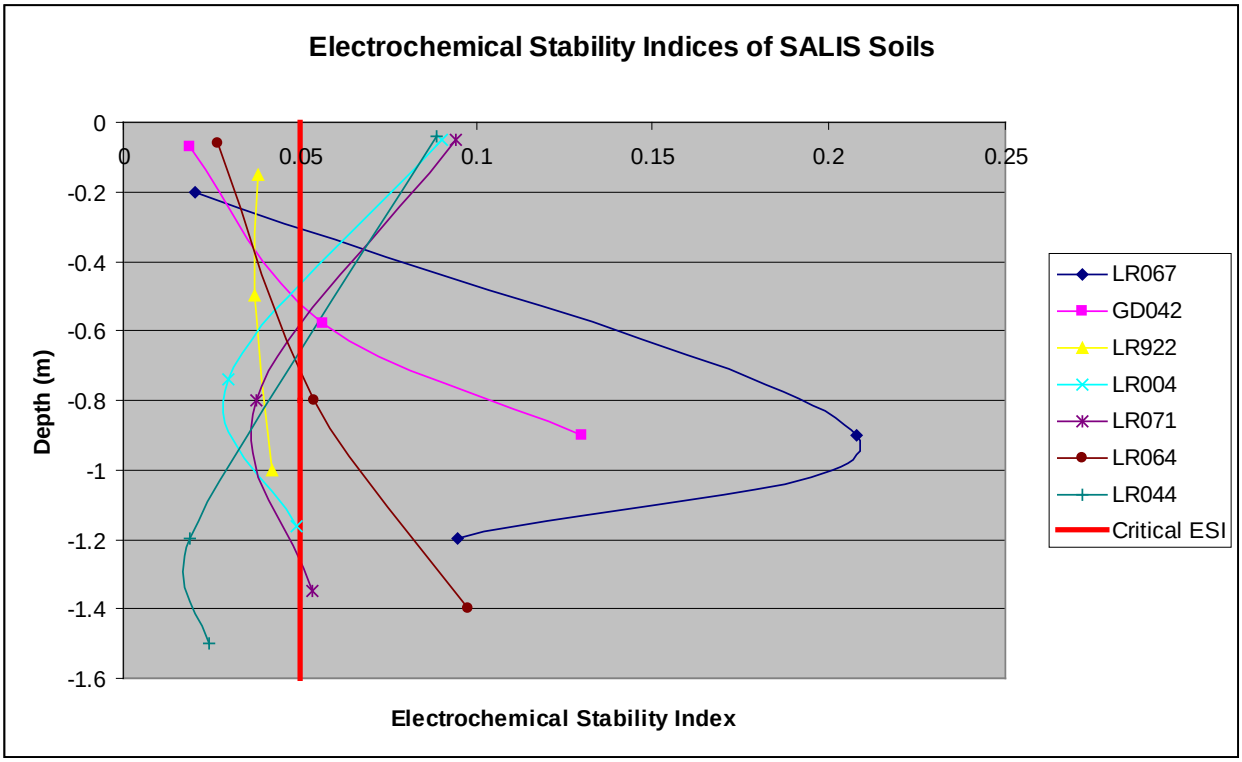
It is also important to note the topography of these soils where the slopes are usually less than 1 per cent. This is an important consideration since this combined with low infiltration rates can mean that water can remain on the land for extended periods of time. The flat nature of the soils is also indicative of the erosivity of these soils. Once an erosion process starts, the erosive nature of these soils means that they will continue to erode until the slope of the eroded material is reduced to a level which the soil can withstand more water flow.

Sodicity and the Electrochemical Stability Index

Soils are considered potentially dispersive when the exchangeable sodium percentage (ESP) is greater than 6.0. An excess of sodium ions between clay layers attracts large amounts of water and breaks the bonds between the clay particles, causing dispersion. Dispersive soils can be highly erodible. As can be seen in Table 1, only one sample in the surface layer had an ESP value greater than 6 but all of the lower layers had ESP values greater than 6. This indicates that lower layers in these Vertosols are potentially very dispersive and erodible when they are exposed. This is also the case in the Namoi Valley.

While sodicity, or the percentage that sodium comprises the cation exchange capacity, is commonly used as an indication of dispersiveness and hence aggregate stability, more information can be gleaned from the electrochemical stability index (ESI), calculated as $EC_{1:5}$/ESP (Anderson et al. 1999; Hulugalle and Finlay 2003). This takes into account the electrical conductivity of the soil which could counter the effects of dispersion in the soil. A critical value of 0.05 is commonly used. An ESI value of less than 0.05 indicates soil dispersion problems (Anderson et al. 1999). The ESI for the soils outlined in Table 1 have been calculated and graphed in Figure 1. It should be noted that a significant number of floodplain soils which have been surveyed have ESI values less than 0.05, indicating potentially dispersive soils.

Figure 1. Electrochemical Stability Indices of the seven soil samples from the SALIS database



Problems encountered with mining on Lightning Ridge Floodplain soils

1. Catastrophic failure of mines

The Knightlife opal field had examples of catastrophic failure of what appeared to be currently worked opal mines. This area was subjected to inundation in 2011 and a number of currently worked and closed opal mines had collapsed.

Figure 2. A worked mine at Knightlife opal field suffering collapse after inundation

Figure 2 shows a mine which has collapsed after inundation of the site with water. It can be seen in the photo that the mining equipment has collapsed into the hole. The soil has been flowing into the existing mine space.

Figure 3. A close crop of Figure 1 showing the void into which the soil is moving

Figure 3 provides detail of the void into which the soil is moving. This photo also clearly shows the delineation of the two soil types, with a narrow band of ridge soil underneath the alluvial soil. During inundation, a significant amount of soil from the roof of the void may have fallen in so the thickness of the ridge soil is not necessarily indicative of the thickness of these soils when they are mined.

Figure 4. The same site viewed from a different angle.

Figure 4 shows the same mine site from a different angle. In this photo, you can clearly see cracks from unstable soil in the foreground. This indicates that, if left to its own devices, this site would continue to erode significantly over time. This collapse is likely to continue until the slope of the soil is slight enough that it is able to withstand further erosion.

Figure 5. Another mine failure at Knightlife opal field

2. Collapse and instability of rehabilitated mine sites

Current practices involve filling in the existing mine shaft with dirt then covering it with a pile of mine spoil. While this works on mines in the ridge soils, the continued degradation of the soil below in the mine void causes collapse of the soil at the surface.

Figure 6. Collapse and instability of a mine void which had been covered over

Again, this would be expected to be an ongoing process until the soil in the mine reaches equilibrium. Without remediation, this site will continue to slump, forming a crater and causing danger to the landholder and their livestock.

3. Collapse of nine inch exploration holes

In addition to the mines, nine inch (229 mm) pilot holes are also regularly drilled. This practice is covered under existing prospecting conditions. Although there are no lateral drives to create voids, once covered, these holes can subside much like the mines except at a much smaller scale. This can result in small holes which could break the legs of cattle or horses if they stepped into them.

Figure 7. Example of collapse of a rehabilitated nine inch exploration hole

4. Disintegration of the inside of the mine shaft

Due to the cracking nature of these soils, when a mine shaft is augured, the sides of the shaft dry out when exposed to air. The soil on the side of these shafts goes through the same shrinkage process as the surface of the soil. This results in the soil breaking off in layers. It appears that there are two processes occurring, firstly, the breaking off of the initial layer which has been compacted by the auger. This can crack off in relatively small (20-30 cm squared) pieces. After this breaks off, larger pieces, up to 70cm long and 30 cm wide seem to proceed to break off.

Figure 8. Inside of an augured mine shaft showing clay shrinkage and pieces ready to fall off

Figure 9. Larger pieces of soil falling away in layers once the compacted inner layer has gone. As new soil is exposed, this process could conceivably continue for an extended period of time

5. Reported instability of mining activity on floodplain soils

Reports were given of people on the surface able to feel the ground moving when mining activities were occurring below. The feeling was that these mines were quite unstable and unsafe.

Vertosols can have cracks extending to at least two metres in vertical depth. At around four metres depth, slickensides can begin to occur. These slickensides are shear planes which the soil can move across. This means that there is likely to be very little to no structural stability through this section of the soil profile and all of the strength in the mine roof will have to be born by the layers below the Vertosols. These layers will also have to bear the weight of the unstable soil above. It is beyond the scope of this report to comment on the engineering structural stability of these mines but it is recommended that an investigation be conducted to determine the limits of stability.

Concerns of the landholders

The landholders present outlined a number of concerns they had with mining on the Vertosols:

- Death and injury to livestock. When this country is wet, these mines are unstable and stock can fall down the eroded mine shafts.
- Safety when mustering stock on this country. The subsided areas can be difficult to see, particularly if there is a heavy covering of grass. Crashing into subsidence areas on bikes, four wheel drives or horses are legitimate concerns and there have been several reports of near misses to date.
- Safety when this country is inundated with water. The landholders revealed that these sites are inspected for stock when the floodplains are inundated with water and during this time, the mines are both unable to be seen and can be almost like quicksand, resulting in dangerous conditions.
- Safety for stock and personnel when riding horses through areas of rehabilitated exploration country (where nine inch exploration holes have been previously drilled). These holes can collapse, leaving a small hole which could break the leg of a cow or a horse.
- Environmental concerns. The erosion events are not only unsightly but also are a sign of environmental degradation which results in long term or permanent loss of productive land.

Are there solutions to these problems?

1. Safety problems

While inspecting the sites, there were examples of what looked like stable mine sites. These sites were built on a pad of stable mine spoil, raising the entrance of the mine to above inundation level and ensuring that free water could not access cracks for several metres away from the mine shaft.

Figure 10. An apparently stable mine entrance at Knightlife opal field

There were also examples where corrugated iron collars extended all the way down the shaft in an attempt to prevent the cracking and gradual collapse of the alluvial soils. There were also cases where the collar was raised and a cement slurry had been installed around the collar in an attempt to stabilize the surrounding soil (figure 11).

Figure 11. Raised collar with a surrounding concrete slurry to stabilize the surrounding soil

While these methods appeared to provide stability to the mineshaft, the subsurface instability due to slickenslides remains. It remains to be seen how well this innovative improvement would stand up to an inundation event where the ground is submerged for an extended period of time. Also, when subjected to wetting and drying cycles, these soils will move, making the foundations for surface structures unstable.

With respect to the instability of Vertosols as an overbearing soil, this is a question which would be best put to an engineer proficient in dealing with Vertosols. It should be noted that there are many instances experienced engineers competent in engineering on soils other than Vertosols who have designed structures which have been catastrophic failures on these soils. An engineer experienced in working on this type of soil is needed to make these recommendations.

2. Erosion problems

There seems little to prevent severe erosion of poorly designed mines or poorly rehabilitated mines on floodplain soils. These soils are likely to erode quickly if they are allowed to start, with severe localised consequences. These problems are severe enough to recommend that mining not continue on these soils until an adequate guideline for confidently rehabilitating these sites is developed.

3. Rehabilitation problems

After the mines have reached their useful life, rehabilitation still poses a problem. If there is any ingress into the mine itself, these soils will keep eroding until the mine and shaft has been filled to a point where no more soil can move into the voids and the soil surface has settled to a stable slope. This is a process which is likely to take decades to complete, the length of time depending on the amount and type of rain falling. This is clearly an unacceptable situation, leaving dangerous holes in the ground which landholders and their livestock can fall down. Options for overcoming this problem could include either filling the entire shaft to 1m depth with mine spoil then covering with topsoil, or fencing the areas off until the area has settled sufficiently.

Conclusions

Current mining practice causes localised environmental problems through erosion and a range of safety issues potentially putting miners and landholders in danger, both in the mining phase and the rehabilitation phase. While there appears to be a range of innovations which have been implemented to alleviate these issues, there is currently not enough sufficient evidence to confidently say these issues have been fixed.

These cracking clays have been formed under very different processes to the ridge soils and consequently behave very differently. Their swelling and shrinking nature when they wet and dry means that the top 2 metres of the soil profile is constantly moving and provides an unstable base for fixtures on the surface of the mine. Slickensides further down the profile mean that shear planes are formed, enabling the soil to slide across these planes. These two properties mean that there is likely to be very little structural integrity in the soil over the opal mine. Consulting with an engineer experienced in dealing with these soils is recommended to obtain more information about this aspect.

Problems encountered during rehabilitation also remain unresolved. Existing rehabilitation methods result in the soil eroding into the void and continuing to erode unless remediation measures are taken. The nature of the soils means that even with remediation, the chance of further degradation years or even decades into the future is high.

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