Environmental review of the Radium Hill mine site, South Australia

Umwelt-Revision des Radium-Hill-Uranbergbaugeländes, Südaustralien

BERND G. LOTTERMOSER, PAUL M. ASHLEY, Australia

Abstract

The Radium Hill uranium deposit, in semi-arid eastern South Australia, was discovered in 1906 and mined for radium between 1906 and 1931 and for uranium between 1954 and 1961 (production of 969,300 t of davidite ore averaging 0.12 % U_3O_8). Rehabilitation was limited to removal of mine facilities, sealing of underground workings and capping of selected waste repositories. In 2002, gamma-ray data, plus tailings, uncrushed and crushed waste rock, stream sediment, topsoil and vegetation samples were collected to assist in the examination of the current environmental status of the mine site. The preliminary data indicate that capping of tailings storage facilities did not ensure the long-term containment of the low-level radioactive wastes due to the erosion of sides of the impoundments. Moreover, active wind erosion of waste fines from various, physically unstable waste repositories causes increasing radiochemical (up to 0.94 µSv/h) and geochemical (Ce, La, Sc, Th, U, V, Y) impacts on local soils and sediments. However, measured radiation levels of soils and sediments are at or below Australian Radiation Protection Standards (20 mSv/a averaged over five consecutive years). Additional capping and landform design of the crushed waste and tailings repositories are required in order to minimise erosion and impacts on surrounding soils and sediments.

Kurzfassung

Die Radium Hill Uranlagerstätte befindet sich im semiariden, östlichen Südaustralien. Die Lagerstätte wurde im Jahre 1906 entdeckt und von 1906 bis 1931 auf Radium und von 1954 bis 1961 auf Uran abgebaut. Die Gesamtproduktion betrug 0,9693 Mio. t Davidit-Erz mit einem Gehalt von 0,12 % U_3O_8. Die anschließende Sanierung beschränkte sich auf die Demontage von Anlagen und Gebäuden, die Verwahrung von Schächten und das Abdecken von wenigen ausgesuchten Halden. Im Jahre 2002 wurde das ehemalige Bergbaugelände auf Gammastrahlung untersucht und Tailings, Haldenmaterial, Sedimente, Böden und Vegetation beprobt, um den gegenwärtigen Stand der Sanierung festzustellen.

Das Bergbaugelände von Radium Hill mit den ehemaligen Aufbereitungsanlagen und Betriebseinrichtungen nimmt eine Fläche von 100 ha ein. Unzählige Abraumhalden befinden sich neben den ehemaligen Schächten über eine Streichlänge von 800 m entlang des Erzgangs. Diese stabilen Abraumhalden bestehen aus Gesteinsmaterial der Grubenbaue. Erzreiches Gestein (0.1 bis 0.2 % U) ist dabei charakterisiert durch Konzentrationen von Fe-Ti-Oxidmineralen (einschließlich Davidit), hohe Strahlenniveaus (maximal 5000 cps, maximal 4,2 µSv/h) und ausgeprägte Anreicherungen an Ce, La, Nb, Sc, Th, Ti, U, V und Y. Gesteinsmaterial der Lagerstätte ist in mehreren Abraumhalden der ehemaligen Aufbereitung und des Bergbaubetriebes zu finden. Feinkörniges Material ist dabei deutlich radioaktiver und reicher an Ce, La, Sc, Th, U, V und Y als grobkörniges und ungebrochener Abraum. Mehrere Halden enthalten feinkörnige Tailings aus Absetzanlagen, die mit verwittertem Gestein und Bodenmaterial abgedeckt worden sind. Die Tailings besitzen erhöhte Strahlungswerte (1400 bis 5500 cps, maximal 3,5 µSv/h) und ausgeprägte Anreicherungen von Ce, La, Sc, Th, U, V und Y. Vor der Abdeckung in den 80er Jahren fand eine Abwehung der Tailings um die größte Tailings-Halde (0,5 Mio. t) statt – feinkörniges Material ist auf mehrere Kilometer auf der Leeseite der Halde eingetragen worden. Bodenkontamination wurde auch durch das beabsichtigte Zumischen von Gesteinssplitt und durch die Dispersion von Oberflächenwässern verursacht. Zusätzlich sind ungedeckte Abraumhalden, die feinkörniges Material enthalten, der Erosion durch Wind und Wasser ausgesetzt und es ist offensichtlich, dass größere Regenfälle den Transport von sogar grobkörnigen Gesteinsbruchstücken auf Hunderte von Metern verursachen. Auf dem Bergbaugelände, dem ehemaligen Stadtgebiet und der Umgebung ist fein- bis grobkörniges Gesteinsmaterial für die Abdeckung von Betriebsarealen, zum Straßenbau (als Zuschlag für Asphalt) und für Betonbauten benutzt worden. Daher sind das Bergbaugelände, das Stadtgebiet sowie einzelne Straßen als deutliche U-Th-Anomalien auf regionalen radiometrischen Karten zu erkennen (Lufterkundungsdaten).

Die Daten weisen darauf hin, dass eine physikalische Dispersion von Tailings und feinkörnigem Abraum in lokale Böden und Sedimente stattgefunden hat. Das Abdecken der Absetzbecken hat den langfristigen Einschluss des schwach radioaktiven Abraums wegen Erosion der Abraumhaldenflanken nicht sicherstellen können. Außerdem verursacht eine aktive Winderosion feinkörniger Rückstände aus den verschiedenen, mechanisch instabilen Abraumhalden erhöhte radiochemische und geochemische Einträge (Ce, La, Sc, Th, U, V, Y) in lokale Böden und Sedimente. Jedoch liegen die Radioaktivitätswerte der kontaminierten Böden und Sedimente an oder unter den australischen Grenzwerten (im Durchschnitt 20 mSv/a über fünf aufeinander folgende Jahre). Eine zusätzliche Abdeckung der aus Gesteinsmaterial und Tailings bestehenden Halden ist notwendig, um die Einträge auf umliegende Böden und Sedimente zu reduzieren.

A/PROF. DR. BERND G. LOTTERMOSER,
A/PROF. DR. PAUL M. ASHLEY,
School of Earth Sciences, James Cook University,
Earth Sciences, University of New England, PO Box 6811,
Cairns, Queensland 4870, Australia Armidale,
New South Wales 2351, Australia
www.jcu.edu.au

1 Introduction

Australia has been a significant uranium producer since 1954, with first generation (1954 to 1971) uranium mines previously operating in the Northern Territory (South Alligator Valley, Rum Jungle), Queensland (Mary Kathleen) and South Australia (Radium Hill). These mines have undergone rehabilitation immediately upon or well after mine closure. Environmental reviews of the Rum Jungle [1, 2] and Mary Kathleen [3, 4] mine sites have revealed the varied success of the applied rehabilitation efforts. Rehabilitation strategies and environmental impacts of individual mine sites thereby depend on the mineralogical and geochemical properties of the ore as well as local hydrological and climatic factors. For example, Australia's uranium deposits are located in widely different climates, ranging from monsoonal tropical to semi-arid conditions. In the wet and seasonally wet climates, acid mine drainage development and the leaching of waste repositories are dominant pathways of contaminants into surrounding environments (e.g. Rum Jungle, Mary Kathleen) [5]. In fact, a number of studies on Australia's uranium mine sites located in these wet climates have highlighted the importance of sulphide oxidation, AMD generation and leaching processes [1, 2, 3, 4]. In comparison, there is little knowledge of the status and environmental impacts of rehabilitated uranium mines in dry climates. Dust generation and waste erosion are likely of more important consideration in arid regions [6]. This study aimed to assess the current environmental status and potential hazards of the former Radium Hill uranium mine area that is located in semi-arid South Australia.

2 Description of the Radium Hill mine site

2.1 Physical characteristics

The Radium Hill mine site is located 440 km NNE of Adelaide, at latitude 32°21'S, longitude 140°38'E, in the Northeast Pastoral Zone of South Australia (Figure 1). The area lies at an altitude of 220 m, with local relief of up 50 m, but generally the area is undulating with substantial plains. The study area is drained by ephemeral creeks and their tributaries, which in turn flow into the major watercourse of the district, Olary Creek. It is only after heavy rain events that there is surface water flow, but it is evident that these events are the major cause of erosion and sediment transport in the region. Soils are commonly skeletal loams on the hills, but thicken into red duplex and calcareous earth on the plains. Calcrete development is common in all non-alluvial soils.

Fig. 1: Location map of the Radium Hill mine site

The climate is semi-arid, with an irregularly distributed and erratic rainfall, averaging 200 mm per annum. Evaporation greatly exceeds rainfall and surface water is generally absent. Average temperatures in the district range from a January maximum of 33 °C to a July minimum of 3 °C [7]. Consequently, vegetation is relatively sparse, with saltbush and bluebush species, native grasses and small trees including mulga, black oak and false sandalwood. River red gums occur along some of the major ephemeral streams. Land use is dominated by low density grazing.

2.2 Radium Hill mine

2.2.1 History

Uranium was discovered at the site of Radium Hill in 1906. Mining occurred intermittently for radium between 1906 to 1931, but due to the need to locate uranium for the then incipient atomic age, an exploration program commenced in 1944, leading to the development of an underground mine, with uranium production commencing in 1954 [8]. Mining continued till 1961, with production of 969 300 t of davidite ($(Ce,La,Ca)(Y,U)(Ti,Fe)_{20}O_{38}$) ore, averaging 0.12 % U_3O_8. This was beneficiated on site to a concentrate that was subsequently railed for treatment at Port Pirie to produce 852 t U_3O_8, plus by-product rare earths and scandium oxide [9, 10, 11]. Mining occurred to a depth of 290 m and along a maximum strike length of 915 m in a series of vein-like lode systems averaging 1 m in width, but up to 7.5 m wide [10]. Although mineralisation was intersected in drill holes to a depth of 450 m, reserves of easily accessible ore were negligible.

Leading up to the commencement of mining in 1954, a substantial town and industrial site was constructed, with the town eventually having a population of approximately 1000. The town was located about 3 km WNW of the mine/industrial site. Following closure of the mine, most buildings were transported away or demolished, leaving only foundations. However, a few of the larger concrete structures remain. Waste rock and mill tailings dumps were simply left uncovered. Due to the semi-arid climate and propensity for windy conditions (particularly from the NW to SW quadrants), the finer mill tailings material was consequently subject to wind deflation, leading to spreading of wind-deposited tailings about the main tailings dam. Due to this condition, capping of mill tailings material with a soil layer was instigated in the early 1980s.

2.2.2 Geology

Uranium mineralisation at Radium Hill is hosted in high grade metamorphic rocks of the Willyama Supergroup, within the Olary Domain. These are of Palaeoproterozoic age (~ 1700 Ma) and include metasedimentary quartzofeldspathic gneiss, composite gneiss, quartz-feldspar-biotite schist and amphibolite.

Several sub-parallel vein-like orebodies (lodes) occupied NE-striking shear zones cutting dragfolds on the overturned western limb of the dome [10]. The lode systems were traced continuously for 1400 m along strike and typically dipped to the SE at 30°-70° [8]. The lodes occupied shear structures containing abundant biotite and quartz, with patchy to nodular aggregates of oxide minerals. The latter form complex intergrowths and include ilmenite, rutile, magnetite, hematite and davidite [12]. The ore is largely refractory (oxides), with only trace amounts of sulphides (pyrite, chalcopyrite, galena, molybdenite). PARKIN & GLASSON [8] noted that lode development was commonly wider and of better grade where lodes intersected amphibolite. In such zones, strong biotite (-oxide mineral) alteration is commonly evident. Lode zones were also associated with lode-parallel and cross-cutting pegmatite and "aplite" masses and were cut by later amphibolites. Surface oxidation effects are relatively minor and the oxide material forming the ore was refractory; minor carnotite occurs as a replacement of davidite.

3 Methodology

Samples of mine waste dump material, mill tailings and crushed rock derived from the mine, topsoil, stream sediments and vegetation were collected from the former mine and town sites, and at background sites several kilometres from the mine. Sample sites were measured by gamma-ray spectrometry and scintillometry, with all samples being analysed for a range of major elements (Ca, Fe, K, Na, Ti) and trace elements (Ag, As, Au, Ba, Br, Ce, Co, Cs, Cr, Cu, Eu, Hf, Ir, La, Lu, Mo, Nb, Pb, Rb, Sb, Sm, Sn, Sc, Se, Ta, Te, Th, V, W, U, Y, Yb, Zn, Zr) by instrumental neutron activation analysis and X-ray fluorescence spectrometry. In addition, selected ore, waste and tailings samples were characterised for their mineralogy using petrography and X-ray diffraction.

4 Results

4.1 Imagery

The Radium Hill site is prominent on aerial photographs. Apart from obvious cultural remnants (e.g. roads, railway, building foundations, large concrete structures), the waste rock dumps, crushed rock dumps and tailings dams are conspicuous. Uncovered material has a grey colour with a blue tint, whereas soil coverings are pale orange-brown. The wind-borne dispersion plume of fine tailings about the Main Tailings Dam (MTD) is evident for several hundred metres distance (except to the SW), causing a pale grey-blue colouration to the soil.

Radiometric imagery of the region reflects bedrock geology and regolith, but the U channel also clearly demonstrates the effects of environmental dispersion (Figure 2). Diffuse U channel highs to the N, NE and ENE of the mine and town sites are most likely due to outcropping bedrock. The mine area has an intense U channel high, with the sharp anomaly being sub-circular and about 1.8 km in diameter. Away from the mine site, there is a diffuse weak U anomaly extending to the east and south for at least 0.7 km and this is interpreted to be in part due to the dispersion of wind-borne tailings. A slightly less intense U anomaly (with three high lobes) occurs over the town site. The gravelled road extending about 1.8 km ENE of the town and the asphalt road between the town and the mine form prominent U anomalies. The former town site and main roads stand out due to the use of mine-derived crushed rock for construction.

On the Th channel, the immediate mine site also forms a prominent anomaly, but less than 1 km in diameter. The town site is hardly discernable on this image, but bedrock and subcrop areas to the N, ENE and immediately S of the mine form prominent diffuse anomalies.

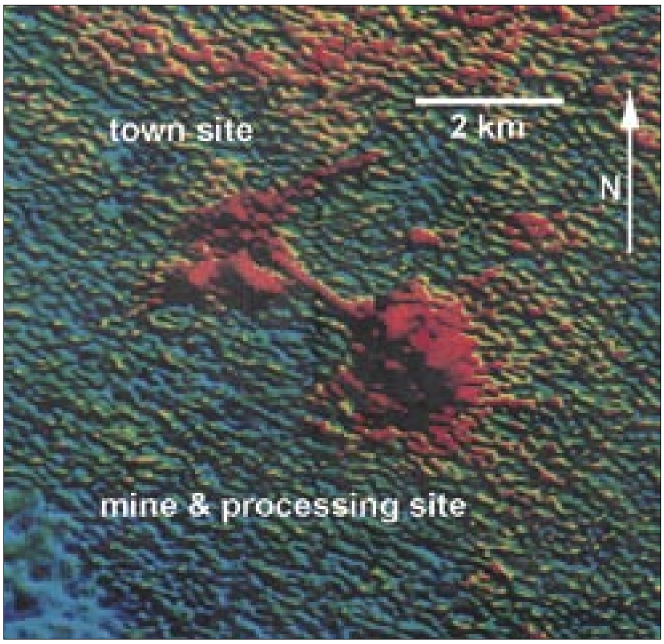

Fig. 2: Radiometrics (uranium channel) of the Radium Hill site showing the distinct U enrichment of the town and mine-processing sites and the main road connecting both areas

4.2 Site description

4.2.1 Remaining infrastructure

The Radium Hill mine site and associated processing area cover an area of approximately 100 ha. It encompasses numerous relicts and foundations of buildings and other structures, although the only substantial remains are those of the main orepass and crusher, plus two large concrete ore bins, adjacent to the former main shaft and mill site. Several roads serviced the area, as well as a rail siding near the mill. Throughout the mine/industrial site, township and local area, fine to coarse crushed rock from the mine has been used for ground cover at worksites, roads (including as a component of asphalt) and for concrete structures.

The asphalt road linking the town to the mine used fine crush material and many other roads leading away from the town and mine used coarse crush material for surfacing. Coarse crush waste rock was also used as railway ballast along the length of the 18 km spur line from Radium Hill to the main Broken Hill-Port Pirie railway and on the latter route prior to the standard gauge railway being opened in 1969. Hence, regional airborne radiometric data outline the town and mine site as well as the local roads as pronounced U-Th anomalies (see Figure 2).

4.2.2 Waste rock dumps

Numerous waste dumps of uncrushed rock occur adjacent to former shafts over a strike length of ~ 800 m elongate along the trace of the line of lode; these are up to 5 m thick and cover individual areas of up to 1 ha. Evident ore grade material (0.1 to 0.2 % U) is characterised by aggregates of Fe-Ti oxide minerals (including significant davidite), high radiation levels (max. 5000 cps; max. 4.2 µSv/h) and distinct Ce, La, Nb, Sc, Th, Ti U, V and Y enrichments. Particle size in waste rock dumps varies from several tens of centimetres down to sandy material and these dumps have remained relatively stable.

Crushed rock material from the mine is found in several dumps in the mine and mill areas. The finer crushed material tends to

Fig. 3: Crushed waste rock dump (RHCR10: 427 ppm U; 0.48 µSv/h), with eroded waste materials in the surrounding topsoils and surface sediments

be significantly more radioactive and is distinctly enriched in Ce, La, Sc, Th, U, V and Y than the coarser crushed rock and the uncrushed waste rock. Adjacent to the mill site, there are several dumps of finely crushed rock (commonly < 2 cm grain size), some individually containing up to ~ 40 000 t, as well as smaller dumps of more coarsely crushed waste rock (Figure 3). Collectively, the waste rock and crushed waste rock dumps contain at least 0.1 Mt of mineralised material.

4.2.3 Tailings repositories

There are at least three dumps (dams) in which fine mill tailings have been stored and each have subsequently been largely remedially covered by soil and weathered rock excavated from trenches alongside each dump. A couple of other sites have also been soil covered, but what lay underneath was not ascertained.

The larger tailings dam (MTD) is one of the main foci of this study due to its size and the fact that it was subject to considerable wind and water erosion prior to being capped. The smaller tailings dams are no more than 50 m on a side, whereas the MTD has dimensions of approximately 250 m x 150 m, is at least 5 to 6 m thick and has slopes up to 20° to 25°. The largest tailings repository contains approximately 0.5 Mt of tailings averaging 200 ppm U. The tailings possess elevated radiation levels (1400 to 5500 cps; max. 3.5 µSv/h) and pronounced Ce, La, Sc, Th, U, V and Y enrichments. The capping material is approximately 1 m thick and composed of relatively consolidated soil, with minor weathered rock and calcrete. Prior to capping, it is alleged that radioactive wastes from a number of other locations were buried in the MTD. The surface is now partly vegetated by saltbush and acacia species, although the steep sides are relatively bare and have been subject to local water erosion, thus exposing bedded fine tailings in places. At one corner of the small tailings dam near the mill site, erosion of the cover has again exposed bedded tailings (Figure 4).

4.2.4 Impacts of waste repositories on soils and sediments

Wind and water dispersion of tailings and crushed rock dumps has occurred and remains active at uncovered sites. Prior to covering in the early 1980s, wind deflation was evidently significant about the MTD (Figure 5) and fine tailings material has been dispersed downwind in all directions. Wind-blown tailings material up to tens of centimetres thick is common up to 80 m away on the NE and SE sides of the MTD, but thinner further away and on the NW and SW sides. Small amounts of windblown tailings remain evident for at least 500 m distant on the SE side of the MTD. The dispersion to the NE and SE reflects the direction of the prevailing strong winds, although E of the MTD, the dispersion plume has probably been largely removed by subsequent flooding of a wide stream channel.

Fig: 4: Erosion and incision into a covered uranium mill tailings repository. The tailings (30.6 mSv/a) were originally (1950s to 1960s) placed into a depression of crushed waste rock and then capped with soil containing calcrete and rock fragments. The soil cover reduces the radiation levels to 0.91 mSv/a as measured at the cover's surface.

Contamination of soil by mine-derived material includes admixing and covering by wind- and water-borne mill tailings, resulting in topsoils adjacent to the main tailings dam having > 90 volume % of tailings material (with approx. 3 x Ce, 4 x La, 2 x Sc, 2 x Th, 3 x U, 3 x V, 2 x Y above background values). Geochemical analyses of topsoils show the decrease in values of U, V, Ce and Sc and increasing Ca (i.e. calcrete in soil) with increasing distance away from the Main Tailings Dam (MTD). Wind and water dispersion of mill tailings and crushed rock away from the MTD has physically added the above elements to the regolith, with values decaying away from the sources.

Uncovered dumps of fine crush rock remain susceptible to wind and water erosion and it is evident that major rainfall events have caused movement of even coarse crush waste rock for hundreds of metres. However, measured radiation levels of contaminated soils and sediments are at or below Australian Radiation Protection Standards (20 mSv/a averaged over five consecutive years).

It is important to note that the waste rock materials and tailings are essentially free of sulphide minerals. It is estimated that sulphides constitute < 0.1 % by volume of these materials. With the prevailing low rainfall and high evaporation rates, infiltration of rain and surface waters into the dumps is probably low, with leaching reactions and seepages of leachate solutions being minimal. Sparsely disseminated fresh pyrite occurs on waste rock dumps

Fig. 5:
View from the top of the capped Main Tailings Dam (MTD) towards the SE. Variable amounts of windblown tailings are present in local topsoils due to wind deflation prior to capping of the MTD.

and has essentially remained unoxidised after several decades exposure to the atmosphere.

5 Conclusion

The environmental review of the Radium Hill uranium mine site in semi-arid South Australia has revealed:

- Soil and sediment contamination (Ce, La, Sc, Th, U, V, Y) has been identified at the mine site covering an area of > 1 km^2 and is largely due erosion of waste repositories since mine closure.
- Geochemical dispersion into soils and sediments from former waste dumps and tailings dams is exclusively by physical means (wind and water erosion).
- The ore is refractory (oxide dominant), has a very low sulphide content and together with the dry climate, has mitigated against any sulphide oxidation, acid mine drainage and chemical dispersion.
- Radiation levels from most media are not significant, bearing in mind the remote location and good ventilation. However, exposure of mill tailings by future erosion could become much of a substantial issue as tailings generally have the highest radiation dose. The current covered tailings dams do not have long-term geomorphic stability and are already subject to rill erosion and might, in the future, be subject again to significant wind erosion.
- A long-term management strategy must require capping of waste dumps and reconfiguration of the main tailings dam to a stable landform.

Acknowledgements

The authors acknowledge support by the Australasian Institute of Mining and Metallurgy Gold 88 Endowment Fund, Australian Institute of Nuclear Science and Engineering (grant no. 03/075), Primary Industries and Resources South Australia (Alistair Crookes), and Alexander von Humboldt Foundation.

Literature

[1] Richards, R.J., Applegate, R.J. & Ritchie, A.I.M. (1996): The Rum Jungle rehabilitation project. – In: Mulligan, D. (Ed.): Environmental Management in the Australian Minerals and Energy Industries 1996: pp. 530-553; University of New South Wales Press.

[2] Taylor, G. et al. (2003): The medium-term performance of waste rock covers – Rum Jungle as a case study. – In: Farrell, T. & Taylor, G. (Eds.): 6th International Conference on Acid Rock Drainage 2003: pp. 383-397; Australasian Institute of Mining & Metallurgy.

[3] Lottermoser, B.G., Costelloe, M.T. & Ashley, P.M. (2003): Tailings dam seepage at the rehabilitated Mary Kathleen uranium mine, northwest Queensland, Australia. – In: Farrell, T. & Taylor, G. (Eds.): 6th International Conference on Acid Rock Drainage 2003: pp. 733-738; Australasian Institute of Mining & Metallurgy.

[4] Costelloe M.T., Lottermoser, B.G. & Ashley, P.M. (2000): Environmental review of the Mary Kathleen uranium minesite, northwest Queensland. Abstracts – no. 59: 99 – of the 15th Australian Geological Convention, 2000; Geological Society of Australia.

[5] Zuk, W.M. et al. (1994): From Rum Jungle to Wismut – reducing the environmental impact of uranium mining and milling. Proceedings of the 9th Pacific Basin Nuclear Conference 1994: pp. 935-940; Institution of Engineers Australia.

[6] Lottermoser, B.G. (2003): Mines Wastes: Characterization, Treatment and Environmental Impacts: 274 pp.; Springer.

[7] Forbes, B.J. (1991): Olary, South Australia, Sheet SI 54-2 (1991); South Australia Geological Survey 1:250 000 Series Explanatory Notes.

[8] Parkin, L.W. & Glasson K.R. (1954): The geology of the Radium Hill uranium mine, South Australia. – Economic Geology, 49: 815-825.

[9] Parkin, L.W. (1965): Radium Hill uranium mine. – In: McAndrew, J. (Ed.): Geology of Australian Ore Deposits: Vol. 1, pp. 312-313. Eighth Commonwealth Mining & Metallurgical Congress Australia & New Zealand 1965; Australasian Institute of Mining & Metallurgy.

[10] Blissett, A.H. (1975): Willyama Mount Painter and Denison Inliers. sundry mineralisation in South Australia. – In: Knight, C.L. (Ed.) Economic Geology of Australia and Papua New Guinea 1. Metals 1975: Monograph 5, pp. 498-505; Australasian Institute of Mining & Metallurgy.

[11] McKay, A.D. & Miezitis, Y. (2001): Australia's Uranium Resources, Geology and Development of Deposits: Geoscience Australia (2001), Mineral Resource Report 1.

[12] Whittle, A.H.G. (1959): The nature of davidite. – Economic Geology, 54: 64-81.