

Erionite in New Zealand: A Risk Assessment for Central Interceptor

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ABSTRACT

Erionite is a naturally occurring asbestiform zeolite mineral. The main geological occurrences of zeolites are in tuff, tephra and volcanoclastic rocks deposited in deep ocean basins subject to low temperature hydrothermal alteration or burial diagenesis. An emerging body of research in Europe and North America has established erionite as carcinogenic to humans. Inhalation exposure to erionite fibres may result in increased risk of malignant mesothelioma. In Auckland, the presence of erionite in tuffaceous and volcanoclastic layers of Waitemata Group sedimentary rocks has been known since the late 1970s, however, neither an occupational exposure limit nor an approved code of practice for handling and disposing of erionite containing materials have been developed in New Zealand or internationally. Watercare's Central Interceptor project is one of several large infrastructure projects in Auckland that handles and disposes of large volumes of Waitemata Group rocks. In the absence of approved guidance, Watercare commissioned Jacobs New Zealand to establish the risks erionite posed to the project. Borehole logs and photographs from the Central Interceptor were reviewed to identify samples with the highest probability of containing erionite for laboratory testing. The accuracy of laboratory tests available in New Zealand and internationally were assessed against the soil guideline values for friable asbestos. Quantitative X-Ray Diffraction testing was considered suitable to screen samples for the presence of erionite. Quantitative X-Ray Diffraction identified one possible occurrence of erionite from thirty-seven samples tested. Consequently, the Central Interceptor project implemented a series of recommendations to limit inhalation exposure of erionite fibres to site workers during construction. Fluidized Bed Asbestos Segregator (FBAS) sample preparation techniques, developed in the United States, used with Transmission Electron Microscopy (TEM) offer detection of erionite in concentrations comparable to soil guideline values established for asbestos. FBAS with TEM may prove fundamental in assessing presence of erionite in the future, once an occupational exposure limit and an approved code of practice for handling and disposing of erionite containing materials have been developed.

Keywords: Risk Assessment, Erionite, Central Interceptor, Auckland, New Zealand.

1 INTRODUCTION

Erionite is a naturally occurring asbestiform zeolite mineral (Brook, 2019). The main geological occurrences of zeolites are in tuff, tephra and volcanoclastic rocks deposited in deep ocean basins subject to low temperature hydrothermal alteration or burial diagenesis (Christie, 2002; Hay and Sheppard, 2001; Marantos *et al.*, 2012). An emerging body of research in Europe and North America has established erionite as carcinogenic to humans (Carbone *et al.*, 2011; Van Gosen *et al.*, 2013; Giordani *et al.*, 2017). In Auckland, the presence of erionite in tuffaceous and volcanoclastic layers of Waitemata Group sedimentary rocks has been known since the late 1970s (Sameshima, 1978), however, neither an occupational exposure limit nor an approved code of practice for handling and disposing of erionite containing materials have been developed in New Zealand or internationally (Brook, 2019). In light of the emerging research and the significant volume of tunnelling and excavation programmed within Waitemata Group rocks the Ministry of Business, Innovation and Employment awarded the University of Auckland funding to investigate the risks posed by erionite on a national scale (MBIE, 2020) and Watercare Services Limited (Watercare) commissioned Jacobs New Zealand Limited (Jacobs) to establish the risks erionite posed on a project-scale for the Central Interceptor. The aim of the project-scale study was to: establish how erionite forms, understand where erionite is distributed in the Auckland region, identify risks erionite posed to the project, and recommend practical risk mitigation controls that could be implemented during construction.

2 ZEOLITES

2.1 What are zeolites?

Erionite is a naturally occurring asbestiform mineral that belongs to a group of aluminosilicate minerals called zeolites (Brook, 2019). Natural zeolites form where volcanic rocks and ash layers react with alkaline groundwater. Zeolites also crystallize in post-depositional environments as secondary minerals

during burial diagenesis and low-grade metamorphism at temperatures below 200°C (Fuoco, 2012). In mafic rocks, rich in iron and/or magnesium, zeolites occur as cavity infills as a result of deposition by fluids or vapours (Rafferty *et al.*, 2020). In sedimentary rocks, zeolites occur as alteration products, cementing detrital material together (Iijima and Utada, 2006).

2.2 Where do zeolites form?

The main global geological occurrences of natural zeolites are in tuffs, tephra and volcanoclastic rocks deposited in deep ocean basins (Hay and Sheppard, 2001). Railton and Watters (1990) assert zeolites hosted in sedimentary rocks are found in three main geological settings in New Zealand: (1) Altered rhyolitic tuffs in lake beds of Quaternary age in the Taupo Volcanic Zone; (2) Marine tuffs and volcanoclastic sandstones of Miocene age in Northland and Auckland; and (3) Weakly metamorphosed marine tuffs and volcanoclastic sandstones of Triassic and Jurassic age in Southland and Southwest Auckland. Only zeolite deposits associated with sedimentary rocks in Northland and Auckland were reviewed, as these formations will be encountered during tunnelling and shaft excavation on CI.

2.3 Why is erionite a concern?

Erionite is an asbestiform fibrous zeolite mineral that is known to be carcinogenic to humans with the potential to cause respiratory disease similar to asbestosis (Brook *et al.*, 2020). If inhaled, erionite fibres can become lodged in various organs of the body such as the linings of the lungs, abdomen, and heart resulting in increased risk of mesothelioma. Compared with other asbestiform minerals, erionite has been shown to have a greater potential to cause fatal respiratory disease than common asbestos minerals typically encountered in industrial use (Rezvani and Bolduc, 2014). At the time of writing, there was no known occupational exposure limit (OEL) for erionite in New Zealand or internationally (Brook *et al.*, 2020).

3 GEOLOGY ALONG THE CENTRAL INTERCEPTOR ALIGNMENT

Understanding the geology along the CI alignment was critical to qualifying the risks erionite posed to the project, as the diagenetic history of Auckland determined how and where zeolites form.

3.1 Provenance of the Waitemata Group

The East Coast Bays Formation (ECBF) of the Waitemata Group is a thick sequence of Miocene-aged sedimentary rock (Edbrooke, 2001) that underlies the entire CI alignment and forms the predominant tunnelling and excavation substrate. ECBF rocks are interpreted as turbidite deposits (flysch) and are characterised by alternating sandstones and siltstones, in various proportions, with less common coarse-grained volcanoclastic sandstones and conglomerates, commonly referred to as Parnell Volcanoclastic Conglomerate (PVC). The origin of the flysch deposits are submarine debris flows, most likely resulting from periodic flank collapse and/or volcanic eruptions along the two bounding volcanic arcs; one currently submerged off the west coast and one to the east, comprising the Coromandel Volcanic Arc (Shane *et al.*, 2010). Significantly, these volcanic arcs and resulting debris flows provided the volcanic ash and andesitic source materials for the formation of zeolite minerals within the ECBF.

3.2 Induration of the Waitemata Group

Though relatively old (approximately 20 million years), ECBF rocks are poorly indurated. Evidence suggests these rocks have not been very deeply buried – perhaps to a maximum depth of 300 m (Edbrooke *et al.*, 1988). Consequently, the materials have never been subjected to the high temperatures and pressures required to fully indurate the sediments. The rocks have been subjected to early rock-forming processes, called diagenesis, which started to break down the constituent sediment components and form a matrix of clay with cementation by zeolites (very low-grade metamorphic minerals) and calcite.

3.3 Known sources of zeolites in the Waitemata Group

Sameshima (1978) noted that zeolites are common throughout Waitemata Group rocks, with the most common occurrence within volcanoclastic and tuffaceous beds and are mainly present as a matrix cement. The most intense zeolitisation occurs in the coarse-grained volcanoclastic sandstones and conglomerate units. Known sources of erionite within Waitemata Group rocks, include: Puketotara, in the Kaipara area, associated with a 90 cm thick tuff bed in the deep marine Timber Bay Formation (Sameshima, 1978); The Tor, Torbay associated with channelised coarse-grained volcanoclastic sandstone deposits; and Caster Bay, Auckland, associated with channelized coarse-grained volcanoclastic sandstone deposits (Rod, n.d.).

4 REVIEW OF EXISTING CENTRAL INTERCEPTOR GROUND INVESTIGATION DATA

Geotechnical investigations commissioned to inform detailed design of CI incorporated petrographic (thin section) and X-Ray Diffraction (XRD) analysis to determine bulk mineralogical properties of the tunnelling substrate. The tests were not commissioned specifically to look for zeolites but results from coarse-grained volcanoclastic sandstone were re-analysed to establish whether there was evidence of erionite in the existing dataset.

4.1 Petrographic review

A review of previous petrographic data was inconclusive. Very few samples of conglomeritic sandstone were examined at sufficient magnification to understand the mineralogy of the finer grains. Consequently, it was impossible to distinguish matrix zeolites from other forms of clay matrix (such as illite). While there was no conclusive petrographic evidence for erionite in the historical CI samples, there was evidence to suggest that zeolite minerals could be present. Many of the volcanoclastic sandstones and conglomerates contained highly altered clasts which represents a potential formation environment for erionite.

4.2 X-Ray Diffraction Review

XRD analysis undertaken for detailed design showed little evidence for zeolites (and therefore erionite), potentially due to the low numbers of samples tested. The XRD results indicated the presence of zeolite minerals chabazite and clinoptilolite in coarser volcanoclastic units, but it was difficult to establish the concentration of zeolite minerals within the sample as the analysis was not quantitative.

5 ERIONITE-SPECIFIC TESTING

5.1 Sampling criteria

CI borehole core logs and photographs were reviewed to identify samples to test for the presence of erionite. Based on the desktop study review, layers of volcanic ash (tuff) deposited within the East Coast Bays Formation and channelised deposits of volcanoclastic sandstone and conglomerates (PVC) have the highest potential to contain zeolites and erionite. Only one possible lens of tuff was identified in CI borehole logs and was sampled for testing. Samples of PVC were selected regardless of whether they were encountered in the tunnel horizon or shaft footprints. Tunnel and shaft excavation could intersect channelised deposits of PVC at any location outside the limits of what is known from current investigation data. A series of control samples were also selected to test for the absence of erionite, the samples were chosen based on their provenance, which was believed to have a low probability of containing erionite.

5.2 Testing methodology

The risks associated with erionite were not widely known when Watercare awarded the Contract to construct CI. This study was commissioned after the contract had been awarded; commencement of shaft excavation was imminent, consequently, a quick turnaround of test results and findings was paramount to establish risks and controls to the project. A survey was undertaken to identify laboratories in New Zealand that could undertake suitable testing to avoid delays associated with international couriering. Panda GeoScience Limited (New Zealand) offered quantitative XRD testing with a detection limit for erionite of 1% weight for weight (w/w) - taken as the weight of the mineral with reference to the weight of the sample tested. Panda GeoScience Limited confirmed quantitative estimates of mineral abundances in terms of major (>20%), minor (~5-20%), and trace (>1% w/w to <~5%) was available via XRD, based on relative peak heights in each sample (Panda GeoScience, 2020). Quantitative XRD was considered suitable for the purpose of the initial screening study, to establish whether erionite might be present in any of the samples and provide an indication to the amount of erionite present.

5.3 Results

Possible erionite was identified in a trace amount (>1% w/w to <5% w/w) in one of the thirty-seven samples tested using quantitative XRD (Panda GeoScience, 2020). The sample (BH 308, 35.6 m to 36.05 m) was obtained from a borehole drilled near the centre of the Manakau Harbour from a depth outside the tunnel horizon. The sample was categorised as PVC and described as slightly weathered, massive, dark grey speckled pink and brown, matrix supported, volcanoclastic CONGLOMERATE, very weak (Jacobs, 2017a). The sample was not considered physically distinguishable from other PVC samples tested. In the other thirty-six samples tested, erionite was not identified above its detection limit, but could perhaps be present in concentrations less than 1% w/w.

6 DISCUSSION

The results indicated erionite could be present in trace amounts (>1% w/w to <5% w/w) in PVC. To qualify the potential risk erionite posed to the project, it was important to understand: the construction techniques proposed for CI, to identify sources of dust; the distribution of PVC along the CI alignment and compare the concentrations of erionite detected against the detection limits and occupational exposure limits for asbestos.

6.1 Central Interceptor construction methodology

CI is a new 14.7km long, 4.5m internal diameter wastewater tunnel. The project also incorporates two link sewers adding a further 4.5km of smaller diameter tunnels. The CI alignment is constructed using a closed-face earth pressure balance (EPB) Tunnel Boring Machine (TBM). The link sewers are pipe jacked using an EPB TBM cutter head. The closed-face EPB TBM removes the tunnel spoil as a wet slurry reducing the amount of dust in the tunnels. Seventeen shafts are to be excavated along the tunnel and link sewer alignments. Conventional earthworks excavators are planned to excavate soil and ECBF rock within shaft footprints, with the exceptions of Keith Hay Park shaft and Walmsley Park shaft, for which shaft drilling techniques are proposed (Jacobs, 2019).

6.2 Distribution of Parnell Volcaniclastic Conglomerate

The distribution of PVC was baselined in the CI Contract Documents, which informed the Contractor to anticipate PVC along 5% of the CI Main Tunnel Alignment and 2% of the Link Sewers. Lenses of PVC, in the order of 5m thick, were encountered in boreholes near Mangere Pump Station Shaft, Walmsley Park Shaft, Haverstock Road Shaft and Haydock Road Shaft. The Contractor should expect to encounter lenses of PVC in the order of 5m thick within the ECBF in these shaft locations. Whilst PVC was not encountered in boreholes near other shaft locations, the Contractor can expect to encounter 5% by volume of moderately strong coarse-to-cobble sized volcanic conglomerate within the ECBF (Jacobs, 2019).

6.3 Comparison of detection limits for erionite and asbestos.

The detection limit for erionite in Quantitative XRD analysis was 1% w/w, which is orders of magnitude greater than the detection limit for friable asbestos or asbestos fines (BRANZ, 2017). The soil guideline values for friable asbestos and asbestos fines in New Zealand is 0.001% w/w i.e., any site with fibrous asbestos >0.001 % w/w requires further assessment (BRANZ, 2017). The guideline value for asbestos fines is orders of magnitude lower than the detection limit for erionite quoted by Panda Geoscience for their XRD-analysis.

7 RISK ASSESSMENT

In light of the results, the anticipated distribution of PVC throughout the scheme, and the proposed closed-face tunnelling methodologies, the probability of encountering airborne erionite in concentrations greater than 1% w/w during tunnelling was considered low. The probability of encountering airborne erionite mineral fibres in concentrations greater than 1% w/w within shaft excavation footprints was considered higher than anticipated in tunnels, primarily because conventional excavators were proposed without dust suppression. The presence of erionite indicated in one sample and the disparity between the detection limits for erionite versus asbestos created uncertainty and warranted construction controls to be implemented during shaft excavation.

8 RECOMMENDATIONS

Construction recommendations were made based on the findings of this study. At the time of writing, there was no known detection limit or occupation exposure limit for erionite in New Zealand or internationally. If an occupational exposure limit for erionite is established during construction, then the controls should be reviewed and amended, as necessary.

8.1 Further testing

It is acknowledged that the number of samples tested was statistically small. To improve the reliability of the test results, Jacobs recommended re-testing at least ten existing samples via Quantitative XRD, one sample must include the sample in which erionite was detected. The Contractor was also advised to collect samples of PVC and tuff encountered during shaft excavation to send for Transmission Electron Microscopy (TEM) testing to further quantify the risks erionite posed to the project team.

8.2 Geological field mapping

The Contractor had undertaken additional site investigation since the CI Contract was awarded. The Contractor was advised to undertake a thorough review of the new (and existing) borehole logs around each shaft location to understand where PVC and tuff is likely to be encountered to enable controls to be implemented in due time. A suitably qualified engineering geologist should be on site during shaft excavation to accurately identify the ground conditions and ensure controls are implemented.

8.3 Air quality monitoring

Jacobs recommended the Contractor contact an IANZ accredited (or equivalent) laboratory capable of undertaking ambient air testing in accordance with ISO 14966:2019 (British Standards Institute, 2019) to see whether the test was suitable for identifying the numerical concentration of erionite fibres during shaft excavation through PVC and tuff. If suitable, periodic air-quality testing was recommended at ventilation egress points to monitor the composition of airborne dust. Similar air quality testing could be undertaken at temporary and permanent spoil sites to identify whether erionite became airborne as spoil heaps dried out. Until an approved code of practice is developed for erionite, the Contractor was advised to review their results of air quality testing against WorkSafe's (2016) approved code of practice for the management and removal of asbestos.

8.4 Dust Suppression

The traditional excavation techniques proposed to excavate shafts did not suppress dust. To minimise inhalation exposure to erionite dust, the Contractor was advised to: use water jets whilst breaking or ripping PVC or tuff beds, cover and moisten temporary stockpiles of spoil, and engage a suitably qualified engineering geologist to accurately identify when the Contractor is encountering PVC or tuff beds.

8.5 Personal Protective Equipment

The Contractor was recommended to seek the advice of an occupational hygienist to establish a suitable face filtering piece (face mask) for staff to wear whilst working with PVC and tuff, which may contain erionite.

8.6 Spoil Disposal

The Contractor was advised to keep spoil moist and covered to minimise dust and was reminded that spoil disposal must meet local authority requirements and resource consent conditions; the presence of erionite in PVC warranted spoil to be disposed of in a landfill licensed to receive asbestos.

9 FUTURE INVESTIGATION

Quantitative XRD offered detection of possible erionite to 1% w/w. Low level detection of mineral fibres has been accomplished using polarized light microscopy (PLM) providing detection limits around 0.25% w/w (Berry *et al.*, 2019). Fluidized Bed Asbestos Segregator (FBAS) sample preparation techniques, developed in the United States, used with Transmission Electron Microscopy (TEM) offer detection of erionite in concentrations of 0.0003% w/w (Berry *et al.*, 2019), which is comparable to soil guideline value established for asbestos fines 0.0001% w/w (BRANZ, 2017). Moreover, FBAS with TEM enables the distinction between fibrous and crystalline erionite, which is key, as only fibrous erionite is classified as a carcinogen (Berry *et al.*, 2019). FBAS with TEM may prove fundamental in assessing concentrations of erionite in the future, once an occupational exposure limit and an approved code of practice for handling and disposing of erionite containing materials have been developed.

10 CONCLUSION

The desktop study review indicated coarse grained volcanoclastic sandstones and conglomerates within the Waitemata Group have the highest potential to contain zeolite minerals. Borehole core logs were reviewed to identify samples of coarse grained volcanoclastic sandstone to screen for the presence of erionite. Thirty-seven samples were tested via Quantitative XRD, one sample detected a trace amount (>1%w/w <5%w/w) of erionite. The distribution of coarse grained volcanoclastic sandstones across the project footprint was estimated to be less than 5% of the total excavation volume. Exposure to dust on CI is suitably mitigated during tunnelling by using an earth pressure balance tunnel boring machine, but workers would be exposed to dust during traditional shaft excavation. Whilst the probability of encountering fibrous erionite in concentrations greater than 1% w/w was considered to be low, the possible presence of erionite in one sample, the disparity between the detection limits for asbestos

versus erionite via XRD testing and the lack of approved guidance created uncertainty. Consequently, the Central Interceptor project proactively implemented a series of construction controls during shaft construction through PVC and tuff, to mitigate the risks associated with inhalation exposure to erionite. To improve the reliability of future erionite investigations, investigators are recommended to obtain robust data sets, test samples using a range of techniques (XRD, PLM and FBAS TEM) and compare results against known reference materials which have been well classified.

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12 REFERENCES

- Berry, D., Januch, J. M., Woodbury, L. and Kent, D. (2019). Detection of Erionite and Other Zeolite Fibres in Soil by the Fluidized Bed Preparation Methodology. *Microscope*. 2019; 67(4): 147–158.
- BRANZ. (2017). New Zealand Guidelines for Assessing and Managing Asbestos in Soil. New Zealand, Print link. BRANZ Limited.
- British Standards Institute. (2019) Ambient air. Determination of numerical concentration of inorganic fibrous particles. Scanning electron microscopy method. BS ISO 14966:2019. BSI.
- Brook, M.S., Black, P.M., Salmond, J., Dirks, K.M., Berry, T.A. and Steighorn, G. (2020). Erionite in Auckland bedrock and malignant mesothelioma: an emerging public and occupational health hazard? *New Zealand Medical Journal*, Volume 133. No. 1518. New Zealand Medical Association.
- Brook, M.S. (2019). Exposure to erionite: health effects and implications for geotechnical risk management in the New Zealand construction sector. *NZ Geomechanics News*. Issue 98.
- Carbone, M., Baris, Y.I. and Bertino, P., Brass, B., Comertpay, S., Umran Dogan, A., Gaudino, G., Jube, S., Kanodia, S., Partridge, C.R., Pass, H.I., Rivera, Z.S., Steele, I., Tuncer, M., Way, S., Yang, H. and Miller, A. Erionite exposure in North Dakota and Turkish villages with mesothelioma. *Proceedings of the National Academy of Sciences of the United States of America* 108(33): 13618–3623.
- Christie, T., Braithwaite, B. and Thompson, B. (2002). Mineral Commodity Report 23 - Zeolites. *NZ Mining*, Volume 31, 16-24.
- Davidson, K.J.; Black, P.M. (1994). Diagenesis in Early Miocene Waitemata Group sediments, Upper Waitemata Harbour, Auckland, New Zealand. *Geoscience Reports*. Shizuoka University, 20: 135-142.
- Edbrooke, S.W., Crouch, E.M., Morgans, H.E.G., Sykes, R. (1998). Late Eocene-Oligocene Te Kuiti Group at Mount Roskill, Auckland, New Zealand. *New Zealand Journal of Geology and Geophysics*, 85-93.
- Edbrooke, S.W. (2001). *Geology of the Auckland Area*. Lower Hutt: Institute of the Geological and Nuclear Sciences.
- Fuoco, D. (2012). A new Method for Characterisation of Natural Zeolites and Organic Nanostructure using Atomic Force Microscopy. *Nanomaterials* 2012, 2, 79-91.
- Giordani M, Mattioli M, Ballirano P, Pacella P, Cenni M, Boscardin M, Valentini L. (2017). Geological occurrence, mineralogical characterization and risk assessment of potentially carcinogenic erionite in Italy. *Journal of Toxicology & Environmental Health B* 20: 81-103.
- Hay, R.L. (1978). Geologic occurrence of zeolites. In: Sand, L.B.; Mumpton, FA. (eds), *Natural zeolites - occurrence, properties, use*, Pergamon Press, 135-143.
- Hay, R.L. and Sheppard, R. A. (2001). Occurrence of zeolites in sedimentary rocks: an overview. In Bish, D. L. and Ming, D. W. (Eds) *Natural zeolites: occurrence, properties, applications*. *Reviews in Mineralogy and Geochemistry*, Volume 45, Mineralogical Society of America, 217-243.
- Iijima, A. and Utada, M. (2006). Zeolites in sedimentary rocks, with reference to the depositional environments and zonal distribution. *Sedimentology*. 7(4): 327-357. Wiley Online Library.
- Jacobs New Zealand Limited. 2017a. Central Interceptor Main Project Works Detailed Design Geotechnical Factual Report.
- Jacobs New Zealand Limited. 2019. Central Interceptor Main Project Works Detailed Design Geotechnical Baseline Report.
- Kermode, L. (1992). *Geological of the Auckland Urban Area Sheet R11 Scale 1:50,000*, IGNS Geological Map 2
- Langella, A., Cappelletti, P., de Gennaro, M. (2001): Zeolites in closed hydrologic systems. In: Bish; D.L., Ming, D. W. (eds), *Natural zeolites: occurrence, properties, applications*. *Reviews in Mineralogy and Geochemistry*, volume 45. Mineralogical Society of America, pp. 235-260.
- Marantos, I., Christidis, G.E. and Ulmanu, M. 2012. *Zeolites Formation and Deposits*. *Handbook of Natural Zeolites*. 2012, 28-51.
- Ministry of Business, Innovation and Employment [MBIE]. (2020). 2020 Endeavour Fund Successful Proposals. [Online]. [Accessed 2022.09.30]. Available from: <https://www.mbie.govt.nz/>
- Panda Geoscience Limited. (2020). XRD study of 37 samples from the Central Interceptor for Watercare.
- Rafferty, J.P., Augustyn, A., Latha, G., Mahajan, D., Rodriguez and Tikkanen, A. (2020). "Zeolite". *Encyclopaedia Britannica*, 17 Jan. 2020.
- Railton, G.L.; Watters, W.A. (1990). *Minerals of New Zealand*. New Zealand Geological Survey bulletin 104.
- Rezvani, N., and Bolduc, D.L. (2014). Erionites. *Encyclopaedia of Toxicology* (Third Edition), Academic Press, 2014, 448-452.
- Rod, M. (n.d.) Zeolites and associated minerals from Parnell Grit beds of the East Coast Bays Formation, Auckland. *Essence of Microscope* (NZ)
- Sameshima, T. (1978). Zeolites in tuff beds of the Miocene Waitemata Group, Auckland Province, New Zealand. P. 309-317, In: Sand, L.B.; Mumpton, F.A. (eds), *Natural zeolites, occurrence, properties and uses*. New York, Pergamon Press.
- Shane, P., Strachan, L.J., Smith, I. (2010). Redefining the Waitemata Basin, New Zealand; A new tectonic, magmatic, and basin evolution model at a subduction terminus in the SW pacific. *An Electronic Journal of The Earth Sciences*.
- Van Gosen B, Blitz TA, Plumlee GS, Meeker GP, Pierson MP. (2013). Geologic occurrences of erionite in the United States: an emerging national public health concern for respiratory disease. *Environmental Geochemistry & Health* 35: 419–430.
- WorkSafe. (2016) Approved Code of Practice: Management and Removal of Asbestos.