ENDIX

AFIC ROCK SAMPLES

| Petrological No., N.Z. Geol. Surv. | Catalogue No., U. Cal., Berkeley |
|---|---|
| P30880 | UC760-10 |
| P30880A, B | UC760-3 |
| P30882A | UC760-5 |
| P30882B | UC760-13 |
| P30883 | |
| P30884C, D | |
| P30885B | |
| P30886 | |
| P25018 | |
| P25108 | |
| | UC760-7 |
| P30879 | UC760-4 |
| P30884A, B | UC760-11 |
| P30885A | UC760-12 |
| B30887 | |
| P31239 | UC760-8 |
| P31492 | UC760-9 |
| P31493 | |
| P31494, -5 | |
| P31496 | |
| P31504 | |
| P31695, -6 | |
| P31490A | UC760-2 |
| P31490B, C | |
| P31491 | UC760-6 |
| P31497 | UC760-1 |
| P31234 | |
| P31501 | |
| P31685, -6 | |
| P31694 | |
| P25013 | |
| P25082 | |
| P31242 | |
| P31247 | |
| P31316 | |





# GEOLOGICAL INTERPRETATION OF NGAWHA DEEP DRILLHOLE, KAIKOHE, NORTHLAND (N15), NEW ZEALAND

F. E. BOWEN and D. N. B. SKINNER

New Zealand Geological Survey, Otara

with an Appendix

## BIOSTRATIGRAPHIC NOTES AND FAUNAL LISTS

N. DE B. HORNIBROOK, G. H. SCOTT and A. R. EDWARDS

New Zealand Geological Survey, Lower Hutt

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ABSTRACT

The log of the deep drillhole at Ngawha Thermal Area, Northland, is interpreted as showing at least 1560 ft of Onerahi Chaos-breccia, the top 720 ft containing faunas which are generally older than those of the lower 840 ft. Between this unit and the underlying, highly indurated Permian-Mesozoic argillites of Waipapa Group, there is 170 ft of possibly allochthonous Eocene sedimentary rocks. The thickness of the Onerahi Chaos-breccia is the greatest yet measured for this unit.

Resistivity values of 200 ohms may be identified with the base of the Onerahi Chaos-breccia, while seismic refraction profiles indicate a depth to 'basement' not significantly greater than the depth of Waipapa Group. A deeper basement inferred from gravity measurements can be neither verified nor refuted from the drillhole or regional geologic data.

Minor hydrothermal alteration of the rocks cut by the drillhole suggests a volcanogenic source for some elements and for the heat, but either a rhyolitic or basaltic source is geologically possible. Both permeable reservoirs and the rise of the hot water to the surface are probably controlled by fault zones in the Waipapa Group and the Onerahi Chaos-breccia, the latter forming a very impermeable caprock except where shattered by several post-Miocene faults. Present day thermal activity is almost totally concentrated on only one of these faults at the centre of Ngawha; this would be the only reasonable site for further geothermal exploration.

## INTRODUCTION

In December 1964, the Ministry of Works drilled a hole to 1929 ft about 1 mile west of Ngawha Springs, as part of a reconnaissance investigation of geothermal potential. The hole was sited in a headwaters gully of Taikawhena Stream at the entrance to a disused quarry (Grid ref. N15/352344, 1949 datum) at about 650 ft above sea level. It lies on, or just south of, the line of an east-north-east trending fault along which some of the Ngawha hot springs are located.

Preliminary detailed geological mapping (Skinner, 1966) recognised local areas of Onerahi Chaos-breccia, a superficial chaotic formation emplaced by gravity sliding onto rocks, some as young as Miocene, throughout

North Auckland (Kear and Waterhouse, 1967). Components include diverse lithological types and yield microfaunas ranging from Upper Cretaceous to Oligocene in age. The drillhole at Ngawha penetrated at least 1560 ft of apparent Onerahi Chaos-breccia, a thickness formerly only suspected.

### *Drill Log Compilation*

Three persons were concerned with the logging of the hole. Mr J. Healy logged cuttings and cores from 0 to 1412 ft, and examined isolated cores from below that depth; one of us (D.N.B.S.) logged the hole also from 0 to 1412 ft, and another (F.E.B.) logged it from 1500 ft. Because very different rock types may be side by side in drill cores from the Chaos-breccia, descriptions of any particular core may vary from one geologist to another, depending on which part of the core each examined. Because of this, and because of differences in nomenclature (e.g., 'siliceous' against 'non-calcareous', and 'argillaceous limestone' against 'calcareous mudstone') two logs (one by Mr Healy, the other by D.N.B.S. and F.E.B.) are presented in virtually their original form, without any attempt to reconcile the few instances where the logs differ (Table 1).

Descriptions of cores are distinguished from those of the probably contaminated drill cuttings by being given in capitals. In the right hand log the lithological descriptions of cores down to 1412 ft are followed by a series of letters ("D", "A", "C", etc.). These correspond to typical lithologies (*see* footnote to Table 1) of rocks mapped in the area by Skinner (1966) and correlated with formations of the Mangakahia Group of Hay (1960). In the final column of Table 1 the ages determined by microfaunal assemblages (*see* Appendix) are given beside the lithology sampled. Depth (or depth range where the specific depth is not known) is shown in the central column of the same line

## STRATIGRAPHY

The following sequence is based mainly on the lithological description of cores (50 to 100 ft intervals), paleontological data, and petrological descriptions (Steiner, 1966). Drilling speeds and the driller's comments as to hardness were also used to determine the boundaries between the Onerahi Chaos-breccia and the Eocene rocks, and between the Eocene rocks and the Waipapa Group, because the drill cuttings are almost certainly contaminated by caving-in over at least the upper 1500 ft and thus give only an imperfect picture of the sequence of strata.

### *0–720 ft: Onerahi Chaos-breccia*

Crushed, brecciated and sheared, dark grey, grey, grey-brown, grey-black and green, non-calcareous (sometimes siliceous) to calcareous mudstones, siltstones and shales, with occasional fine, grey-brown, non-calcareous, feldspathic or micaceous sandstones and rare bituminous lenticules. Cataclasis is frequently so advanced that differing components

…erhouse, 1967). Components include …id microfaunas ranging from Upper …ne drillhole at Ngawha penetrated at … Chaos-breccia, a thickness formerly

*Compilation*

…ith the logging of the hole. Mr J. … from 0 to 1412 ft, and examined …n; one of us (D.N.B.S.) logged the …other (F.E.B.) logged it from 1500 ft. …y be side by side in drill cores from …y particular core may vary from one …which part of the core each examined. …ences in nomenclature (e.g., 'siliceous' …ceous limestone' against 'calcareous … Healy, the other by D.N.B.S. and …r original form, without any attempt …ne logs differ (Table 1).

…uished from those of the probably … given in capitals. In the right hand …ores down to 1412 ft are followed … ', etc.). These correspond to typical … of rocks mapped in the area by …ormations of the Mangakahia Group … of Table 1 the ages determined by …ix) are given beside the lithology …re the specific depth is not known) …me line

…APHY

…inly on the lithological description …eontological data, and petrological … speeds and the driller's comments …rmine the boundaries between the … rocks, and between the Eocene …use the drill cuttings are almost …r at least the upper 1500 ft and …ne sequence of strata.

…rk grey, grey, grey-brown, grey- …metimes siliceous) to calcareous … occasional fine, grey-brown, non- … sandstones and rare bituminous …vanced that differing components



TABLE 1 - LOGS, NO. 1 DEEP DRILLHOLE, NGAWHA

| Depth (ft) | Lithology (by J. Healy) |
|---|---|
| 0 - 60 | Grey siliceous shale |
| 60 - 70 | Soft siltstone |
| 70 - 80 | Pale grey-brown calcareous sandstone |
| 80 - 90 | Grey siliceous shale |
| 90 - 100 | Grey siliceous shale and interbedded sandstone |
| 96 - 101 | MODERATELY COMPACTED DARK GREY SILTSTONE AND GREY-BROWN CALCAREOUS SANDSTONE, CRUSHED AND BRECCIATED |
| 100 - 180 | Light to dark grey siliceous shale |
| 180 - 190 | Light to dark grey siliceous shale with softer material |
| 190 - 200 | Dark grey siliceous shale |
| 200 - 206 | 9 in. AS FOR 96 - 101 ft BUT LESS BRECCIATED<br>1 ft 9 in. DOMINANTLY GREY-BLACK MUDSTONE<br>1 ft DOMINANTLY GREY-BROWN FINE SANDSTONE |
| 200 - 250 | Dark grey mudstone |
| 250 - 270 | Grey siliceous shale |
| 261 - 267 | BRECCIATED AND FINELY JOINTED GREY SILICEOUS SHALE, PARTS SLIGHTLY CALCAREOUS. ABUNDANT SMALL RADIATING, FIBROUS ZEOLITES |
| 270 - 300 | Mudstone |
| 295 - 305 | GREY-BROWN SLIGHTLY CALCAREOUS SILTSTONE, WELL JOINTED AND A LITTLE SHEARED |
| 300 - 330 | Grey siliceous shale |
| 330 - 340 | Grey-brown calcareous sandstone |
| 330 - 345 | AS FOR 261-7 ft, BUT FINER AND LESS ZEOLITE A LITTLE PYRITE |
| 340 - 460 | Grey siliceous shale |
| 402 - 407 | AS FOR 261-7 ft |
| 460 - 470 | Cream-grey sandstone |
| 470 - 490 | Grey siliceous shale |
| 475 - 480 | AS FOR 261-7 ft. A FEW SMALL VEINS CALCITE ABUNDANT ZEOLITE |
| 490 - 500 | Dark grey mudstone |
| 500 - 610 | Dark shale and fine sandstone |
| 502 - 508 | AS FOR 261-7 ft, BUT GENERALLY DARKER GREY |

| Depth (ft) | Lithology (by D.N.B. Skinner to 1,412 ft; thereafter by F.E. Bowen) | Microfossil Results |
|---|---|---|
| 0 - 60 | Blue-grey non-calcareous siltstone | |
| 70 | Blue-grey mudstone | |
| 80 - 90 | Blue-grey non-calcareous siltstone | |
| 96 - 101 | GREEN, BRECCIATED SILTSTONE CHIPS IN CRUSHED NON-CALCAREOUS MUDSTONE "D" | Mh - Dt<br>Mh - Dt |
| 100 - 110 | Blue-grey, non-calcareous siltstone and green slightly calcareous mudstone | |
| 120 | Fine sandstone | |
| 130 - 150 | Blue-grey, non-calcareous siltstone | |
| 160 - 200 | Green-grey, non-calcareous siltstone | |
| 200 - 206 | SILTSTONE AND FINE FELDSPATHIC SANDSTONE WITH FLAKES OF MICA "C" | n.d.<br>Mh - Dt |
| 210 - 250 | Green-grey, non-calcareous siltstone and mudstone | |
| 261 - 267 | FINE GREEN, VERY SHEARED AND BRECCIATED CALCAREOUS, SHALY MUDSTONE "A" | |
| 270 | Non-calcareous siltstone | |
| 280 - 290 | Slightly calcareous siltstone | |
| 295 - 305 | SILTSTONE, FINE MICA AND FELDSPATHIC SANDSTONE NON-CALCAREOUS AND ONLY SLIGHTLY BRECCIATED VERY FINE SHALE PARTICLES IN SANDSTONE "C" | |
| 310 - 330 | Blue-grey slightly calcareous siltstone | Mh |
| 340 - 345 | PIECES FINE MICA SANDSTONE AND GREEN NON-CALCAREOUS MUDSTONE IN SHEARED CALCAREOUS SHALE "B" | |
| 350 - 400 | Blue-grey calcareous siltstone and mudstone | |
| 402 - 407 | BRECCIATED CALCAREOUS SILTSTONE IN SHEARED NON-CALCAREOUS MUDSTONE | |
| 410 - 460 | Blue-grey calcareous siltstone and mudstone | |
| 470 | Light grey slightly calcareous siltstone with asphalt chips | |
| 473 - 478 | VERY CALCAREOUS, VEINED AND SHATTERED GREEN-GREY SHALE WITH FIBROUS SHELLY CHIPS "A" | |
| 480 - 490 | Light grey calcareous siltstone | |
| 500 | Dark green mudstone | |
| 502 - 508 | AS FOR 473-8 ft, BUT EVEN MORE SHEARED "A" | Dt |
| 510 - 570 | Blue-grey calcareous siltstone | |

| Depth (ft) | Lithology (by J. Healy) |
|---|---|
| 605 – 609 | GREY-BROWN SILTSTONE, SHEARED AND WITH INTER-LEAVED BANDS OF DARKER MATERIAL |
| 610 – 670 | Dark grey mudstone |
| 700 – 705 | GREY-BROWN SILTSTONE, INTERNALLY SLICKENSIDED |
| 730 – 1412 | Light grey to white argillaceous limestone with some interbedded siliceous shale and sandstone |
| 780 – 786 | SHEARED AND BRECCIATED PALE GREY-WHITE ARGILLACEOUS LIMESTONE |
| 800 – 805 | PALE GREY SHALE, BRECCIATED AND INTERNALLY SLICKENSIDED, WITH BANDS OF DARKER NON-CALCAREOUS SHALE |
| 890 – 892 | A FEW PIECES PALE PURPLE AND WHITISH SILICEOUS MATERIAL WITH SMALL CALCITE VEINS |
| 940 – 946 | BRECCIATED, SLIGHTLY CALCAREOUS AND MODERATELY COMPACTED GREY MUDSTONE |
| 1016 – 1023 | GREY-WHITE COMPACTED CLAYSTONE WITH INTERBEDDED FINE TO MEDIUM SANDSTONE, FINELY BRECCIATED AND CEMENTED WITH QUARTZ AND CALCITE |
| 1058 – 1062 | WHITE, SLIGHTLY CALCAREOUS CLAYSTONE AND SANDY LIMESTONE |
| 1105 – 1110 | BRECCIATED ARGILLACEOUS LIMESTONE |
| 1200 – 1205 | GREY-WHITE ARGILLACEOUS LIMESTONE WITH CALCITE VEINS AND A FEW SMALL PYRITE CRYSTALS |
| 1303 – 1310 | LIGHT GREY BRECCIATED ARGILLACEOUS LIMESTONE SHEARED ALONG PLANES DIPPING 50° AND INTER-BEDDED WITH NON-CALCAREOUS MATERIAL |

| Depth (ft) | Lithology (by D.N.B. Skinner to 1,412 ft; thereafter by F.E. Bowen) | Microfossil Results |
|---|---|---|
| 580 – 600 | Sandstone with asphalt chips and large mica flakos | |
| 605 – 609 | MICA SILTSTONE AND FINE SANDSTONE WITH A LITTLE SHEARED, SLIGHTLY CALCAREOUS MUDSTONE "C" | |
| 620 – 690 | Green, calcareous mudstone, with asphalt at 650-70 ft | |
| 700 – 705 | FINE MICACEOUS SANDSTONE IN GREEN SHEARED SLIGHTLY CALCAREOUS MUDSTONE "C" | n.f. |
| 710 – 720 | Green calcareous mudstone | ?Mh – ?Dt |
| 730 – 770 | Variably calcareous mudstone with asphalt | |
| 780 – 786 | SHEARED, VERY HARD, VERY CALCAREOUS GREY-WHITE ARGILLACEOUS LIMESTONE WITH ASPHALT "A" | |
| 790 | Highly calcareous siltstone with asphalt | |
| 800 – 805 | SIMILAR TO 780-6 ft BUT MORE SHALY, ASPHALTIC | D + Ab |
| 810 – 840 | Light grey calcareous siltstone and mudstone with asphalt | |
| 850 – 880 | Blue-grey calcareous siltstone and mudstone with asphalt at 880 ft | |
| 890 – 892 | HARD WHITE TO GREY SHEARED BUT FIRM ARGILLACEOUS LIMESTONE "A" | |
| 900 – 930 | Asphaltic grey calcareous argillite | |
| 940 – 946 | BRECCIATED, SHATTERED AND VEINED, CALCAREOUS MUDSTONE "A" | |
| 950 – 960 | Asphaltic non-calcareous mudstone | |
| 970 | Very asphaltic calcareous argillite | |
| 980 – 1010 | Argillaceous limestone | |
| 1016 – 1023 | SHEARED CALCAREOUS MUDSTONE WITH PATCHES COARSE ?GLAUCONITIC SANDSTONE WITH SMALL SULPHIDE GRAINS "B" | D? + Ab |
| 1030 – 1050 | Very calcareous mudstone | |
| 1058 – 1062 | VERY SHEARED ARGILLACEOUS LIMESTONE WITH THIN BANDS CALCAREOUS SILTSTONE "A" | |
| 1070 – 1100 | Grey mudstone, progressively decreasing calcareous content | n.d. |
| 1105 – 1110 | SHEARED, MYLONITISED ARGILLACEOUS LIMESTONE | |
| 1120 – 1190 | Blue-grey calcareous siltstone | Dt + Ab |
| 1200 – 1205 | FAIRLY HARD, COMPACT, SHEARED, ARGILLACEOUS LIMESTONE "A" | |
| 1210 – 1300 | Blue-grey calcareous siltstone | |
| 1303 – 1310 | SHEARED GREY-GREEN CALCAREOUS MUDSTONE WITH SMALL BANDS SILTSTONE "A" | Dt + Ab |
| 1320 – 1400 | Blue-grey calcareous siltstone | Dt? + Ab |



| Depth (ft) | Lithology (by J. Healy) |
|---|---|
| 1406 – 1412 | SMALL RECOVERY OF GREY SILICEOUS MATERIAL CONTAINS SMALL PYRRHOTITE CRYSTALS |
| 1597 | HARD GREY-WHITE LIMESTONE WITH INTERNAL SUB-HORIZONTAL SLICKENSIDE PLANES AND PYRITE |

| Depth (ft) | Lithology (by D.N.B. Skinner to 1,412 ft; thereafter by F.E. Bowen) | Microfossil Results |
|---|---|---|
| 1406 – 1412 | VERY HARD, CHERT-LIKE ROCK WITH FINE DISSEMINATED PYRRHOTITE, COARSE ON JOINTS | A? not older than M |
| 1500 – 1515 | SOMEWHAT SHEARED MEDIUM GREY SILTSTONE, DIP PROBABLY LOW | Post C – probably Rt – Mp |
| 1590 – 1598 | LIGHT GREY CALCAREOUS SILTSTONE WITH FRAGMENTS COARSER MATERIAL. DIP 15°. MUCH PYRITE | |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |

| | | | | |
|---|---|---|---|---|
| | ...ATED, SLIGHTLY CALCAREOUS AND MODERATELY COMPACTED GREY MUDSTONE | 900 - 930 | ... SHEARED BUT FIRM ARGILLACEOUS LIMESTONE "A" | |
| | | 940 - 946 | Asphaltic grey calcareous argillite | |
| | | 950 - 960 | BRECCIATED, SHATTERED AND VEINED, CALCAREOUS MUDSTONE "A" | |
| | | 970 | Asphaltic non-calcareous mudstone | |
| 1016 - 1023 | GREY-WHITE COMPACTED CLAYSTONE WITH INTERBEDDED FINE TO MEDIUM SANDSTONE, FINELY BRECCIATED AND CEMENTED WITH QUARTZ AND CALCITE | 980 - 1010 | Very asphaltic calcareous argillite | |
| | | 1016 - | Argillaceous limestone | |
| | | 1023 | SHEARED CALCAREOUS MUDSTONE WITH PATCHES COARSE ?GLAUCONITIC SANDSTONE WITH SMALL SULPHIDE GRAINS "B" | |
| 1058 - 1062 | WHITE, SLIGHTLY CALCAREOUS CLAYSTONE AND SANDY LIMESTONE | 1030 - 1050 | Very calcareous mudstone | D? + Ab |
| | | 1058 - 1062 | VERY SHEARED ARGILLACEOUS LIMESTONE WITH THIN BANDS CALCAREOUS SILTSTONE "A" | |
| 1105 - 1110 | BRECCIATED ARGILLACEOUS LIMESTONE | 1070 - 1100 | Grey mudstone, progressively decreasing calcareous content | n.d. |
| | | 1105 - 1110 | SHEARED, MYLONITISED ARGILLACEOUS LIMESTONE | |
| 1200 - 1205 | GREY-WHITE ARGILLACEOUS LIMESTONE WITH CALCITE VEINS AND A FEW SMALL PYRITE CRYSTALS | 1120 - 1190 | Blue-grey calcareous siltstone | Dt + Ab |
| | | 1200 - 1205 | FAIRLY HARD, COMPACT, SHEARED, ARGILLACEOUS LIMESTONE "A" | |
| 1303 - 1310 | LIGHT GREY BRECCIATED ARGILLACEOUS LIMESTONE SHEARED ALONG PLANES DIPPING 50° AND INTERBEDDED WITH NON-CALCAREOUS MATERIAL | 1210 - 1300 | Blue-grey calcareous siltstone | |
| | | 1303 - 1310 | SHEARED GREY-GREEN CALCAREOUS MUDSTONE WITH SMALL BANDS SILTSTONE "A" | Dt + Ab |
| | | 1320 - 1400 | Blue-grey calcareous siltstone | Dt? + Ab |

| Depth (ft) | Lithology (by J. Healy) | Depth (ft) | Lithology (by D.N.B. Skinner to 1,412 ft; thereafter by F.E. Bowen) | Microfossil Results |
|---|---|---|---|---|
| 1406 - 1412 | SMALL RECOVERY OF GREY SILICEOUS MATERIAL CONTAINS SMALL PYRRHOTITE CRYSTALS | 1406 - 1412 | VERY HARD, CHERT-LIKE ROCK WITH FINE DISSEMINATED PYRRHOTITE, COARSE ON JOINTS | |
| | | 1500 - 1515 | SOMEWHAT SHEARED MEDIUM GREY SILTSTONE, DIP PROBABLY LOW | A? not older than M Post C - probably Rt - Mp |
| 1597 | HARD GREY-WHITE LIMESTONE WITH INTERNAL SUB-HORIZONTAL SLICKENSIDE PLANES AND PYRITE | 1590 - 1598 | LIGHT GREY CALCAREOUS SILTSTONE WITH FRAGMENTS COARSER MATERIAL. DIP 15°. MUCH PYRITE | |
| | | 1693 - 1695 | AS FOR 1590-8 ft. DIP 20° | ?Ab |
| 1699 | HARD, LIGHT GREY, FINE-GRAINED CALCAREOUS SANDSTONE, WITH THIN VEINS OF CALCITE | 1696 - 1697 | MEDIUM BRECCIA | Ab |
| | | 1698 - 1700 | FINE SANDSTONE WITH MINERALISED SHEAR PLANES | Dh + Ab |
| | | 1756 - 1760 | GREEN CHERTY ARGILLITE, RED-BROWN AND BLACK ARGILLITE | n.d. |
| 1761 | HARD, LIGHT AND DARK GREY SILICEOUS ROCK WITH DISSEMINATED SULPHIDES | 1761 - 1769 | DARK BLUE-GREY ARGILLITE WITH THIN QUARTZ VEINS, CHERTY ARGILLITE. DIP c.45° PYRITE | |
| | | 1769 - 1779 | DARK GREY TO BLACK ARGILLITE AND CHERTY ARGILLITE WITH PYRITE | |
| 1820 | GREY, FINE BANDED ARGILLITE. DIP 25° | 1816 - 1820 | DARK GREY AND BROWN BANDED ARGILLITE. DIP 40-45°, SOME PYRITE | |
| 1900 | GREY-WHITE SILICEOUS ROCK WITH SOME CALCAREOUS CONTENT. DIP c.25° | | | |
| | | 1914 - 1924 | GREEN-GREY SILICEOUS ARGILLITE WITH SOME PYRITE | |
| | | 1924 - 1929 | GREEN-GREY SILICEOUS ARGILLITE | |

CORE DESCRIPTIONS IN CAPITALS, cuttings descriptions in lower case.

LETTER CODE FOR LITHOLOGY/FORMATION CORRELATION:

| Code | Lithology | Formation (Hay, 1960) | Age (Hay, 1960) |
|---|---|---|---|
| "A" | Calcareous, grey, white and green mudstone and siltstone, or argillaceous limestone | Titoki Shale | Teurian |
| "B" | Intermediate between "A" and "C" | | Upper Haumurian to Teurian |
| "C" | Micaceous, feldspathic, sandstone, interbedded with siltstone and mudstone | Punakitere Sandstone | Upper Haumurian |
| "D" | Non-calcareous, grey or green shale, shaly mudstone and siltstone. Hard | Ngatuturi Claystone | Lower Haumurian |

LETTER CODE IN MICROFOSSIL RESULTS COLUMN are symbols for standard New Zealand stage divisions.

TABLE 1 reproduced from "Ngawha geothermal area, Northland", N.Z. Geological Survey Report 16.

are intermixed. Calcite is present as veins and cement; the latter is also locally kaolinitic. The sediments have a fresh appearance but occasionally fracture surfaces show minute radial aggregations of thomsonite. There is little pyrite. Faunal ages include both Haumurian and Teurian (Upper Cretaceous and Paleocene), but most are more broadly Haumurian to Teurian (*see* Appendix).

*720–1568 ft: Onerahi Chaos-breccia*

Much sheared and brecciated pale, grey-white, argillaceous limestone; pale, grey-white calcareous shale, siltstone and mudstone with interbedded dark, non-calcareous shale or siltstone, or calcareous sandstone; sandy limestone; purple, grey or white siliceous material; and relatively unsheared grey, somewhat calcareous siltstone. Asphalt lenticules locally present, and the mudstones are bentonitic. Calcite veins are common and there is much pyrite and pyrrhotite both locally disseminated and lining fractures. Calcite is the normal cement but locally both calcite and silica, or silica alone, may be present. Down to 1310 ft mixed Bortonian (Eocene) and Dannevirke (Paleocene) faunas were found in all samples examined, but below that depth older faunas (perhaps as old as Raukumara) were recorded (*see* Appendix).

*1568–1736 ft: Formation uncertain–?Eocene*

Indurated, relatively unsheared, light grey, calcareous mudstone with siliceous bands, and fine sandstone with interbedded fine breccia. Some calcite veins are present and pyrrhotite and pyrite are common, particularly so in the lower part of the sequence. Faunas are Bortonian (Eocene) except at 1697 ft where there is a mixed assemblage of Bortonian and Heretaungan (Dannevirke–Eocene) species (*see* Appendix).

*1736–1924 ft: Waipapa Group*

Reddish brown, black, dark grey, blue-grey and greenish grey argillite, partly silicified and partly recrystallised is correlated with the typical Waipapa Group argillite as exposed in Northland. The rock is intensely sheared, with quartz veins, and younger calcite veins that commonly contain pyrrhotite. Cavities are lined with hydrothermal quartz, and dolomite and much pyrite is disseminated along fracture walls. Dip about 45°.

## DISCUSSION

### *Waipapa Group*

This group of Permian–Mesozoic indurated sedimentary and volcanic rocks has not yet been subdivided. The argillites in the drillhole are similar to those exposed north and east of Ngawha and clearly belong to this basement group.

…s veins and cement; the latter is also …ve a fresh appearance but occasionally …al aggregations of thomsonite. There … both Haumurian and Teurian (Upper …ost are more broadly Haumurian to

…e, grey-white, argillaceous limestone; siltstone and mudstone with inter- …r siltstone, or calcareous sandstone; …nite siliceous material; and relatively … siltstone. Asphalt lenticules locally …nitic. Calcite veins are common and both locally disseminated and lining …nt but locally both calcite and silica, to 1310 ft mixed Bortonian (Eocene) were found in all samples examined, perhaps as old as Raukumara) were.

*…ocene*

…nt grey, calcareous mudstone with …ith interbedded fine breccia. Some …e and pyrite are common, particu- …nce. Faunas are Bortonian (Eocene) …ixed assemblage of Bortonian and …ecies (*see* Appendix).

…ue-grey and greenish grey argillite, …ed is correlated with the typical … Northland. The rock is intensely …ger calcite veins that commonly with hydrothermal quartz, and …ed along fracture walls. Dip about

…ON

*…Group*

…urated sedimentary and volcanic …e argillites in the drillhole are of Ngawha and clearly belong to



### *?Eocene Rocks of Uncertain Formation Correlation*

Important factors in the interpretation of the cores from 1568 to 1736 ft as being autochthonous Eocene (Bortonian) sedimentary rocks are their generally unsheared nature and their lithologies. Elsewhere, similar Bortonian sequences of beds with overlying siltstones rest in place but unconformably on the hard Waipapa rocks. There is very little evidence of post depositional cataclasis. The breccia is interbedded with the sandstone, and is thus of normal intraformational nature.

Despite the lack of prominent shearing, however, these rocks may still be part of a large block of Eocene sediments rafted into position and could therefore belong to the Onerahi Chaos-breccia.

### *Onerahi Chaos-breccia*

This formation consists of a chaotic melange of diverse lithologies varying in size from small grains to massive blocks. Proved exposures have hitherto been confined to eastern Northland at altitudes usually below 250 ft and nowhere more than 550 ft above sea level, whereas at Ngawha the altitude ranges from 700 to 1000 ft above sea level. The known maximum thickness has been about 500 ft, the breccia filling pre-existing valleys or, in some localities (e.g., Kamo, Silverdale, Warkworth), being emplaced in fault-angle depressions soon after faulting movements ceased (Kear and Waterhouse, 1967). It is considered to have been emplaced by gravity sliding, probably under subaqueous conditions, and perhaps as a result of folding or block faulting in its source area or areas, aided by the bentonitic nature of the source sediments. Known examples commonly contain Upper Cretaceous to Oligocene faunas, and at Windy Hill, near Warkworth, the breccia rests on Waitemata alternating sandstones and siltstones of lower Miocene age. A post-Oligocene age of emplacement is thus indicated at many individual localities, and a post-lower Miocene age at one.

The Ngawha drillhole sequence, which is much thicker than that previously recorded for typical Onerahi Chaos-breccia, is divisible into two parts on lithological and paleontological grounds. Disregarding hydrothermal calcite, the lower part is much more calcareous than the upper. It also contains Bortonian faunas mixed with older elements, whereas the upper part contains Mata to Dannevirke faunas only. The time of emplacement is uncertain, but could be as old as Bortonian since no younger fossils have been found (Bowen, 1966).

Because of the nature of the formation and its thickness in the Ngawha region, there can be little hope of interpreting the sub-surface geology from a study of surface exposures.

### *Relation of Drillhole and Geophysical Data*

Of the two major stratigraphic boundaries penetrated by the Ngawha drillhole, that at about 1568 ft between the Onerahi Chaos-breccia and the Eocene sedimentary rocks is best identified with the 200-ohm metre-resistivity values at the base of most soundings reported by MacDonald and Banwell (1965, pp 41–2), although no 200-ohm metre value was obtained at Ngawha itself. These 200-ohm metre readings indicate that a generalised resistivity "basement" increases in depth from north-east to south-west and from north to south. Extrapolation of surrounding values would suggest a theoretical basement at about 1400 ft at Ngawha. The boundary at about 1736 ft between the Eocene sedimentary rocks and the Waipapa Group basement rocks is near the inferred depth of about 2000 ft to "basement" suggested by seismic refraction shots across the area (Banwell, 1965, p. 43).

The increasing depth of basement from north-east to south-west inferred from the gravity data (Banwell, 1965, p. 43) is consistent with the general geology of the area, but the suggestion that the Waipapa Group argillites penetrated by the drillhole overlie "actual" basement at a depth of 3000 to 7000 ft is neither locally nor regionally verifiable. A secondary basement only a few thousands of feet deeper than the bottom of the drillhole would require an abrupt change to rocks of higher density, since burial compaction of sedimentary rocks to the required density is most unlikely within the specified depth range. No such change of density was detected by the seismic investigations, but xenoliths of amphibolite from Whangarei Heads (Bartrum, 1937; Allen, 1951), which may have a significantly greater density than the Waipapa Group (cf. Hatherton and Leopard, 1964), could have been derived from such a basement.

### *Source of Hot Water and Heat*

Without correcting for the relative casing sizes of Ngawha (3 inch) and Wairakei (8 inch), the steam output of the Ngawha hole was about 5% of an average Wairakei hole and the heat flow about 7% of Wairakei (Banwell, 1965, p. 40). The drillhole had a shut-in well-head pressure of 800 p.s.i.g. and a maximum temperature of 236°C at 1800 ft.

Both the natural hot spring and drillhole waters have been shown to have a common geochemical source, the relatively high concentrations of boron, ammonia, bicarbonate and lithium suggesting an origin within the sedimentary rocks of the Ngawha basin (Ellis and Mahon, 1966, p. 452). The "greywackes and argillites" of the New Zealand Permian to Mesozoic geosyncline, of which the Waipapa Group is a part, could also have been a source of the boron and ammonia (Ellis and Mahon, 1966, p. 455).

Both a rhyolitic (Mahon, 1965, p. 38) and a basaltic (Ingham, 1965, pp. 43–5) heat source have been suggested for the Ngawha region, the former on the basis of apparent volcanogenic elements in the hot water, and the latter because of a small positive magnetic anomaly west of the Ngawha centre attributed to a basic intrusion. Although the latest eruptions have been basaltic, Putahi Rhyolite, a probable acid differentiate of a basic magma, is almost certainly Quaternary in age (Skinner, 1966); hence both sources are possible and neither are disproved by the drillhole. A volcanogenic source is possibly suggested by the relatively meagre hydrothermal alteration of the rocks penetrated by the drillhole. Above

720 ft rare thomsonite lining joints, kaolinitic calcite cement, and rare pyrite may be of hydrothermal origin. Below 720 ft the Onerahi Chaos-breccia becomes richer in pyrite and pyrrhotite and the normal calcite cement becomes replaced by silica. Pyrrhotite is particularly common in the lower part of the Eocene sediments and in the Waipapa argillite where it is associated with hydrothermal quartz, dolomite and pyrite. If the sulphides, silica and magnesia are volcanogenic a rhyolitic source may be inferred. However, if they are simply remobilised from the enclosing sediments by rising hot ground-water, the heat source is considered more likely to be basaltic.

The rise of the hot water to the surface has been by way of faults, the presence of which have been inferred in the Kaikohe region from volcanic centre alignment. South-south-east and north-east trends (Kear, 1964, p. 28), and an east-north-east trend (Skinner, 1966) have been suggested; the springs and lakes are also aligned along east-north-east trends (Fleming, 1945, p. 258), confirmed by aerial photograph interpretation. The dips on the fracture systems are probably near vertical (cf. faults at Kamo shown by Kear, 1959) but there is no certain evidence for this in the Ngawha region. Although greywacke sandstone was not encountered in the drillhole, it would perhaps be more permeable than the argillite, particularly if it were fault shattered. Resistivity readings close to the present hot springs showed a 1 ohm value extending to the base of the sounding (McDonald and Banwell, 1965, p. 42) which may imply shattered rock with an appreciable amount of pore fluid.

### *Geological Factors Affecting Geothermal Potential*

Assuming a continuing source of heat and water from below the top of the Waipapa Group, pre-Onerahi Chaos-breccia fault zones would act as permeable/porous reservoirs for hot water/steam, but non-faulted areas would be impervious. Hence any available heat and water would be channelled into the fracture zones. The ?autochthonous Eocene sandstone and breccia could also act as a partial reservoir. However, the tightly jumbled, recemented Onerahi Chaos-breccia sediments would act as a good impermeable caprock through which the hot water could escape only through the post-Miocene east-north-east fault zones that cross the Ngawha basin. Of the springs associated with these fractures, only the central Ngawha springs and a 'kerosene' spring on the shores of Lake Omapere (Skinner, 1966) are still hot, although other hot springs (now cold) were noted by Bell and Clarke (1909) and Ferrar (1934). Present day surface activity is thus almost wholly concentrated about the central 'hot spot' at Ngawha so that any further exploration for geothermal steam must also be concentrated in this area.

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## APPENDIX

### BIOSTRATIGRAPHIC NOTES AND FAUNAL LISTS

N. DE B. HORNIBROOK, G. H. SCOTT (Foraminifera) and A. R. EDWARDS (Nannoplankton)

N15/f702 depth 305 ft: *Dorothia elongata* Finlay, *Rzehakina epigona* (Rzehak); correlation: Haumurian Stage. No nannoplankton present.

N15/f702 depth 508 ft: *Bolivinopsis spectabilis* (Grzybowski), *Gaudryina whangaia* Finlay, *Conotrochammina* sp., *Rzehakina epigona* (Rzehak); correlation: Teurian Stage.

N15/f702 depth 805 ft: *Nuttallides trumpyi* (Nuttall), *Globigerapsis index* (Finlay); correlation: Bortonian Stage. *Globorotalia aragonensis* Nuttall; correlation: Previous records of this species are from middle Dannevirke rocks in Northland. It is likely that the assemblage in this sample is mixed. Nannoplankton: *Coccolithus umbilicus* (Kamptner), *Zygrhablithus bijugatus* (Deflandre), *Discoaster barbadensis* Tan, *Discoaster* spp. of *D. distinctus* group, *Discoaster* n.sp. (minute); correlation (in association): upper Heretaungan to Bortonian. *Discoaster multiradiatus* Bramlette & Riedel; correlation: upper Teurian to basal Waipawan. *Discoaster tribrachiatus* Bramlette & Riedel; correlation: mid Waipawan to Mangaorapan. Assemblage is mixed.

N15/f702 depth 1110 ft: *Nuttallides trumpyi* (Nuttall)?, *Globigerapsis index* Finlay; correlation: Bortonian Stage. The presence of *Bolivinopsis spectabilis* (Grzybowski), *Recurvoides* sp. and *Rzehakina epigona* (Rzehak), characteristic Haumurian–Teurian species; indicates a mixed assemblage. Nannoplankton: *Discoaster barbadensis* Tan: correlation: top Waipawan to Bortonian.

N15/f702 depth 1303 ft: *Glomospira corona* Cushman and Jarvis, *Bolivinopsis* sp., *Haplophragmoides* sp., *Recurvoides* sp., *Cyclammina grangei* Finlay, *Rzehakina epigona* (Rzehak). This is a Teurian assemblage; however, rare specimens of *Gaudryina proreussi* Finlay (Bortonian) suggest that the fauna is mixed. Nannoplankton: *Discoaster barbadensis* Tan; correlation: top Waipawan to Bortonian.

N15/f702 depth 1310 ft: *Discorbinella jugosus* (Finlay) and *Cibicides tholus* Finlay indicate Bortonian. Haumurian–Teurian elements may also be present (*Rzehakina?*).

N15/f702 depth 1406–12 ft: *Anomalinoides* sp. Correlation: possibly Arnold Series; not lower than Mata Series.

N15/f703 depth 1509–15 ft: *Glomospira corona* Cushman and Jarvis, *Ammobaculites* sp., *Recurvoides* sp., *Haplophragmoides* spp., *Hedbergella* sp? This assemblage is post-Clarence Series (*G. corona*) and probably Teratan–Piripauan (*Ammobaculites* sp.).

N15/f704 depth 1591–98 ft: *Vuvulina* sp., *Nuttallides* sp., *Cibicides tholus* Finlay?, *Discorbinella jugosus* (Finlay), *Globigerapsis index* Finlay? Correlation: probably Bortonian.

N15/f705 depth 1694 ft: *Bulimina pahiensis* Finlay, *Nuttallides trumpyi* Finlay, *Discorbinella jugosus* (Finlay), *Globigerapsis index* (Finlay). Correlation: Bortonian Stage.

N15/f707 depth 1697 ft: *Elphidium hampdenensis* Finlay, *Nuttallides* sp., *Globorotalia aragonensis* Nuttall, *Globigerapsis index* Finlay. Correlation: Mixed assemblage of Heretaungan and Bortonian species.

N15/f706 depth 1698 ft: Crushed, indeterminate planktonic species.

In terms of the New Zealand standard sequence, the stratigraphy of Ngawha drillhole is highly disordered. Inversions of faunal sequence occur throughout and mixed assemblages are present in several samples. Derived Haumurian–Teurian arenaceous and siliceous species, notably *Rzehakina*, are commonly found in Arnold–Pareora Series samples from Northland and N15/f702 depths 1110 ft and 1310 ft may be examples of this type of mixed assemblage. Whether the mixed Dannevirke/Bortonian planktonic assemblages of N15/f702 depth 805 ft and N15/f707 depth 1697 ft are of similar origin or due to fine-scale jumbling of strata during deposition of Onerahi Chaos-breccia would require detailed lithological study of cores prior to preparation of microfaunal residues.