Speleogenesis and Karst in New Zealand

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Introduction

The cavernous rocks of New Zealand can be grouped broadly into two main geologic types-the massive, metamorphosed, Ordovician, Mt. Arthour Marble of north-west South Lsland, and the stratified, bioclastic, Tertiary Te Kuiti limestones of western regions of both islands. Ahthough much cave exploration has been carried out in both these regions, the principal study so far has involved caves and karst in the central western portion of North Island near the well-known Waitomo Caves, where some 85km of caves hace been surveyed during the past 12 years by members of New Zealand Speleolgical Society.

Throughout the region from Kawhia Harbour 60km south to Mokau River, and inland 50km to Te Kuiti, the stratigraphic column includes two major limestones of Oligocene to lowest Miocene age. There limestones were proceded by calcareous sandstone and siltstone unconformable on Jurassic rocks, and succeeded by marine siltstone. They constitute Te Kuiti Group (Kear and Schofield) of which the three formations, from lowest upwards, Orahiri Limestone, Waitome Sandstone, and Oterehanga Limestone form Castle Craig Subgroup (Barrett).

Orahiri Limestone is sandy and of bioclastic origin with conspicuous, thick beds of fossil oyster shells (Crassostrea). It is more than 30m thick, and microfacies can be distinguished. To the east and north the 12m thick, glauconitic Waitomo Sandstone overlie Orahiri Limestone, but to the west and south there is only a minor erosional break in sedimentation. The upperment and most extensive formation of Castle Craig Subgroup is the flaggy, purer, bioclastic Otorohanga Limestone which is as much as 40m thick. The overlying 20m contains beds of silty limestone here called Ruakuri member. Other thin Tertiary limestones are found in this region, for example at Oparure and Te Anga. Correlatives of the Te Kuiti Group limestones are mainly on the west of New Zealand, and extend as far as whangarei Limestone at Waiomio 340km north, and Awarua Limestone at Milford Sound 900km south. All are indurated by cementation and recrystallisation.

The post-Jurassic land mass of this region is assumed to have had a more mature topography than that developed on the Jurassic rocks today, and coastal embyments did exist. When marine transgression began from the north during the lower Oligocene, several shallow basins were formed, and scattered thin pebble beds indicate that the land mass to the west did not introduce much terriginous material. The small shallow embayments were later engulfed in a larger deeper basin some 50km across. This continued to fill with bioclastic limestone until the lowest Miocene when an orogeny commenced giving angular unconformities between the younger formations and finally the cessation of marine sedimentation in this region. The orogeny raised Jurassic rocks to form Herangi Range from the southern portion of which the Tertiary marine formations dip away to east, south and west while to the north the eastern slopes are cut by a series of north trending step faults, and to the west the Tertiary rocks have been stripped off by erosion.

In contrast Mt Arthur Marble is homogenous in composition. It is found in a region extending 200km south from Cape Farewell and is uplifted to an altitude of almost 1900m with a rugged alpine karst topography.

KARST

A comparison of New Zealand karst with the well-known regions of the world indicated that climatic conditions have been similar. Most of the characteristic features of karst topography are found in New Zealand, and Mt Arthur Tableland in South Island is an excellent example of a holekarst plateau. In North Island the region south-west of Waitomo is basically merokarst, but with some important differences.

Firstly, the region is rent by a number of major north-trending faults only a few kilometres apart. There is also a conspicuous joint alignment at about 60° to these fault. This influences not only cave patterns but also outcrop alignments. Secondly, because the region is blanketed with volcanic debris, which includes Pleistocene ignimbrites, the outcrops are only found in steepsided valleys, and any plateau that might exist has not yet been uncovered by erosion.

The third most striking feature of karst outcrops in the New Zealand Tertiary limestones is horizontal flagginess. The best known example is found on the West Coast of South Island at Punakaiki. The material between the limestone flags is known as a residual bed or seam. Two origins have been proposed, but neither answers all the charcteristics observed so far. Kear and Schofield considered the seams to be simple depositional features involving sand occasionally interbedded with the more abundant shell fragments, but this does not explain why some seams cross obvious depositional beds. Barret considered "that the seams originated as a result of postdepositional intrastratal solution, acting along definite, predominantly horizontal planes in the rock", but also admitted that there was "no satisfactory explanation for the constant relationship between purity of the limestone and the spacing of the seams, or for the regularity of that spacing"

Speleogenesis

Most New Zealand caves in Tertiary Limestone are of vadose origin, with dendritic plans and several entrances. Cave ceilings rarely meet with the regional water table. The formation of cavities is controlled by two major factors. Firstly, the solubility of the limestone, with which are associated the aggressiveness of the water, and the ability of the stream to remove solid waste products. The purest limestones are either densely crystalline and easily fractured to allow solution to proceed, or porous enough to preclude preferred patterns of flow. Sandy limestones produce a different pattern of speleognesis because every fracture that allows movement of water also allows the introduction of insoluble sand or silt to obstruct flow and curtail further development. When more than 35% insolubles are presant cavern development does not take place in the Te Kuiti Group limestones. Secondly, the regional pattern of jointing and faulting, and to a lesser extent the dip of the strata. The Waitome district is dissected by a series of five major faults each downthrown about 30 to 40m to the east. These faults allow most of the subterranean streams to resurge over an impermeable bed that has been exposed, and thus preclude phreatic development. Other fault arends are to the east-north-east, and most of the jointing is in this direction. the strata dip at no more than 10° , and bedding plane cave passages are rare. Near Mokau a number of down-dip caves are found in the steeply dipping limestone. At Takaka, South Island, a cave in very steeply dipping Tertiary limestone is strike-controlled along the water table.

The two principal limestones of Te Kuiti Group show field distinctions in karst and speleogenesis related to their lithologies. The younger Otorohanga Limestone is very pure (excluding Ruakuri member) and of bioclastic origin. Sparry recrystallisation of constituents shows preminently in microscope thin sections. Horizontal seams are spaced at about 5cm and produce the flagginess of outcrops. Verical joints are aligned with regional patterns and spaced at 0.5 to 1.5m. Minor joints within flags are widened by solution to narrow crevices, and these combine with horizontal development of anaistomosis to form spongework. High, narrow passages of vadose origin twist tortuously, usually uninfluenced by regional trends of faults and dip, for example the Wriggley Passage in Millars Waterfall Cave. Stream gradients are often steep with drops at passage junctions where the altitudes may vary by as much as 10m. Phreatic development, now abandoned, has left solution grid patterns, for example Organ Left of Glow-worm Cave. No present day submerged grid pattern caves are known. Scallop markings are common in some of the caves of phreatic origin on the main Waitomo Stream, for example, Waitomeo Waterfall Cave with an almost circular resurgence and Gardners Gut Cave which resurges through a joint widened by solution. No hydrological studies have yet been completed.

The older Orahiri Limestone (including Waitome Sandstone which in many places in rich enough in calcium carbonate to be called a limestone) shows cave patterns developed along major joints. Because the limestone is less crystalline it is more competent to accommodate stresses. Herizontal seams are spaced at about 10 to 15cm, and vertical joints are observed at spacings of several metres. The intricate spongework found in Otorohanga Limestone is not observed. Horizontal flow of water is at first by seopage through the sandy seams between the flags, then anastomosis develops immediately below, Speleogenesis on a large scale appears to proceed principally by corrosion of widened joints, for example Ruakuri Cave, but an excellent corrosion grid pattern is found in The Maze Cave, 6km north of Waitome. When there is sufficient flow of water to remove residual silt and sand. the normal degradation of the stream bed is modified by abrasion of the walls by water-borne solids that help remove the softer strata. The stream gradients are about 1 in 30 with few single drops of more than 1m. Sometines a deposite of iron and manganese exides pretects the leached rock from further dissolution and fine abrasion.

The development of vertical shafts within the limestone is associated with seepage of aggresive water into the vadose zone directly from a soil horizon, or from a perched water table such as Ruakuri member provides, for example, the 64m shaft (teme) into Ruakuri Cave near the inner tourist bridge. The shaft (aven) in Glew-worm Cave is not open to the surface.

Other New Zealand regions show different types of speleogenesis. Mt. Arthur Marble with only minor impurities tends to joint in massive blocks which make vertical shafts common. Several of these shafts are more than 260 m deep, ad the deepest so far explored is Harwood Hold, Takaka, 368m. Cave development is modified by moraine, talus, and river boulders brought from high mountain country, and on some of the steeper forested slopes vee valley erosion takes place. The very porous bioclastic limestones of east coast districts of North and South Islands show very little speleogenesis, although near Pareora, South Island, a spectacular pattern of dolines is found.

Cave Fill

Four main types are considered :

First : The residual silt and sand, left by pressure dissolution during compaction of impure limestone, is found between the flags, A section north of Waitomo shows 20% of the present thickness to be of this type. In situ leaching of subterranean surfaces also produces a similar residue. In the lower levels of Waitomo district the residual beds form fins which protrude as much as 10cm, indicating interlocking of grains and possibly bonding with non-calcareous cement. Some examples contain gypsum, others palygorskite, both either foreign to the limestone, or indicating a substantial amount of dissolution. Fins have not been observed in Otorohanga Limestone. Much of the fine mud of caves, and the buff colour of stalactites are attributed to clay impurities in the limestone.

Second : Pebbles and sand from weathered Jurassic sandstone are brought into caves at Waitome by streams rising in the Herangi Range to the west. Silt and clay from the overlying Miocene siltstone also enter caves in large quantities because the relief is more than 300m and the valleys are steep sided. Waitomo Stream is rarely clear of suspended silt. Barrett and Harris dated the microflora from cave fill at Kairimu (near Te Anga) as early Pleistocene with some redeposited Oligocene. Caves on the West Coast, South Island, are often cheked with granite boulders from post glacial rivers. In all districts soil from weathered limestone slumps into shakeholes. The Waitomo polije contains some 20m of alluvium which is probably associated with the aggradation of the lower Waitomo Valley which occurred either by an influx of volcanic debris, or a post-glacial rise in sea level, The present flood plain in the polje is controlled by the restriction of the Glow-werm Cave. No explanation is available at present for the alluvial fill in Aranui Cave which remained for some considerable period at 25m above the level of the ploje.

Third : Volcanic products. Boulders of rhyolitic ignimbrite from the scarps of nearby flews, are to be found in caves south of Waitomo. Most of the region has been buried beneath several metres of Pleistocene ash showers which appear in cave fill as high shrinkage mud containing montmorillonite, or as blank titanomagnetite sand.

In a country only recently cleared of its indigenous forest, and often disturbed by major earthquakes, it is difficult to know how much collapase is caused by unnoticed natural processes, how much by catastrophic events, and how much by man's interference with the delicate balance of nature. One large rockfall in Paparahia Cave (near the coast 50km south-west of Waitomo) is attributed to an earthquake of January 1962. Where a cave ceiling is in laminated impure limestone, exfoliation forms domes with complementary talus mounds on the floor, if no stream is available to remove the debris, for example, Metro Cave, Nile River, South Island.
Fourth : Speleothems. No extensive crystallographic studies avebeenmade in New Zealand. Only a few chemical analyses and descriptive accounts are available. Visiting speleologists have commented on the profusion of calcite speleothems in New Zealand caves. The usual diversity of stalactites and stalagmites is found, but the colours are limited to white, cream, yellow brown and rarely red or black. Current studies by Hendy using radioactive isotopes, indicate that the most vigorous periods of calcite deposition are related to glaciations. Helictites are found in sheltered

chambers. Aragonite has not been determined. Gypsum is not profuse, but some spectacular growths are found in dry passages like Flower Cave (30km south-westof Waitome). The limestone is not gypsiferous, and the crystals originate from the seams between the flags. A platy gypsum stalagmite has been found in Wet Neck Cavern, Paturau, South Island. Amerphous silica has been recorded as a fine fluffy powder associated with gypsum, and palygorskite is sometimes found as a thick leathery bed between limestone flags.

REFERENCES

BARRETT. P. J. 1963, The Development of Kairimu Cave, Marakopa District, South-West Auckland. N. Z. Jl Geol. Geophys. 6, 2: 299-98

BARRETT. P. J. 1964 Residual Seams and Cementation in Oligocene Shell Calcarenites, Te Ku Group. Jl Sediment. Petrol. 34, 3: 524-31

BARRETT. P. J. 1967 Te Kujti Group in the Waitomo - Te Anga Area. N. Z. Jl Geol. Geophys. 10, 4: 1009-26

Kear, d. ; Schofield, J. C. 1959 Te Kuiti Group. N. Z. Jl Geol. Geophys. 2, 4: 685-717

KERMODE, L. O. 1966 Speleology in New Zealand. N. Z. Speleol. Bull. 3, 60 : 489-536