Maars
Their characteristics, varieties and definition

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Volcanoes are mostly positive landforms, that is hills projecting above a general ground surface. Craters and calderas however, are negative landforms, depressions below the general level of the surrounding ground surface, and they may hold lakes. Some volcanic depressions have been called « maars », a name used locally for the volcanic crater lakes of the Eifel region in Germany. Unfortunately, it is not at all clear what the term « maar » means in geomorphic or vulcanological literature. Does it apply to the lake, to the depression or to the entire landform including the rim? As a technical term, « maar » has taken on ill-defined attributes of form, genesis and material; it may suggest an incipient volcano, a tuff ring, a low-rimmed crater, a crater rim consisting of fragmented country rock, a shallow volcanic lake, a landform resulting from volcanic/phreatic explosion, or carry numerous unrelated implications.

Some of the criteria involved will now be considered.

1. *Lake present or not*

Although the original meaning of maar is a lake, even in the Eifel there are « dry maars », and the presence, or even former presence of a lake is not essential for the « maar » landform. As FRECHEN (1959) has said,

> « Sometimes in local speech only the water-filled craters are called maars. This designation is too narrow, as the water has no direct connection with the volcanic formation of the maar ».

2. *Deep or shallow*

Some maar lakes are deep. Pulvermaar (Eifel) is 74 m deep. Bullenmerri (S.E. Australia) is 75 m deep at present and in the past has been 100 m deep, at which level it overflows. As water level may vary for many reasons the difference in height between the upper edge of bedrock and the deepest point in the maar bottom is a better indication of crater depth, though variable within any one maar because it depends upon the relief of the land surface before the formation of the maar. Maxima in the Eifel are Meerfelder 212 m, Ge-

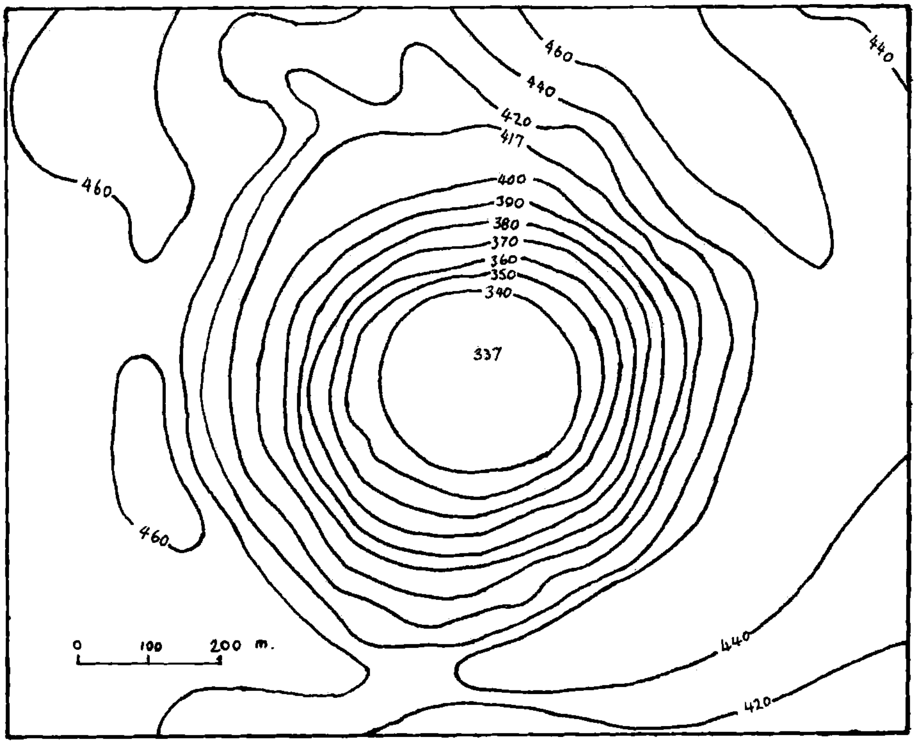

FIG. 1 - Pulvermaar. Contour figures in metres. From HOPMANN, FRECHEN and KNETCH, 1959.

mundenermaar 204 m and Weinfelder 137 m. Other maars are shallow or dry, many with flat bottoms. Depth is therefore not an important criterion in defining maars.

3. *Low or high rim*

Many authorities (such as HILLS, see p. 63) write of « low tuff rings » and « low ramparts » as if lowness was one of the definitive characteristics of maars, but in fact some high rims are known. Besides actual height there is the implication of low angles of slope in low rims.

Ulmenermaar (Eifel), Tritriva (Madagascar) and Diamond Head (Hawaii) are examples of maars with high and steep-sloped rims. Although height and steepness cannot be used to define the whole class of maars, they are, however, very useful for subdivision. Nevertheless maars that arise on valley sides, such as Gemundener maar and the Dreiser Weiher have marked differences in height in upper and lower rims and complicate the subdivision.

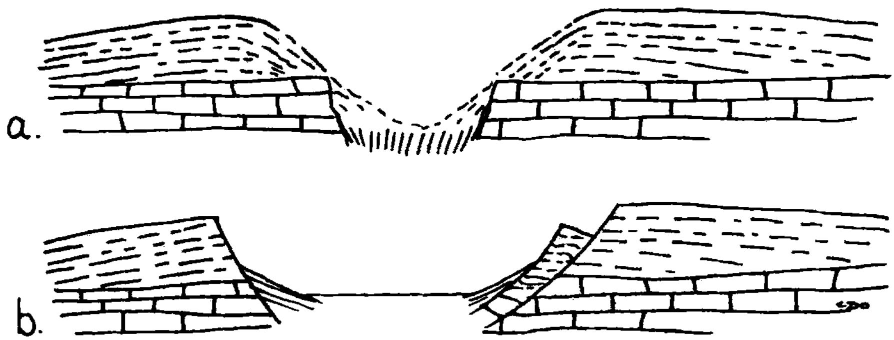

FIG. 2 - Diagram, not to scale, of slumping in maars. Probably all eruptions produce some inward dipping tuff as in (a). A certain amount of slumping into the crater is necessary (b) to account for those maars with only outward dipping tuff.

4. *Wide or small*

The diameter of maars has not been defined, but they are usually larger than simple volcanic craters as in scoria cones, and smaller than calderas. Perhaps the smallest maar is the Hutsche maar (Eifel) which is only 70 m across but of dubious origin. Trautzberger-maar is 100 m and Durresmaar is 270 m, but most maars are over 400 m across. The largest maars are about 1.5 km across; Meerfelder, the largest of the Eifel maars, for example is 1.4 km across, but Tower Hill (S.E. Australia) is 3 km. There is however a distinct difference between the size of the largest maars, and that of calderas, which are normally 5 km or more in diameter.

5. *Circular or not*

The great majority of maars are roughly circular but for various reasons a few are irregular. Bullenmerri (S.E. Australia) is actually a coalescence of three maars and has a clover-leaf shape. Leg of Mutton Lake, Mount Gambier (S.E. Australia) is irregular because of the interference of the rim of one maar with another. Maars of the Rubirizi volcanics (Uganda) have irregular shapes because they are erupted through very rugged country. The tuff ring at Mt. Leura (S.E. Australia) has a distinct angle in it, possibly reflecting bedrock structure. Lakes may of course, lose their circular shape as they dry up, and the shape of the surrounding rampart is what is really under consideration. Since there is no specific level at which the shape of the rampart should be measured it is futile to talk too precisely about slight deviations from circularity. If one takes as a reference line the outcrop of bedrock rather than the accidental water level line, it gives a dominantly roundish or oval shape for the Eifel maars. Pulvermaar is almost circular, Immerathermaar is somewhat elongate.

6. *Symmetrical or asymmetrical rim*

The majority of maars have rims of markedly asymmetrical section, with gentle outer slopes, steep inner slopes and a rounded crest. In the exceptional case of the Hawaiian maars, however, both inner and outer slopes are steep, and meet in a fairly sharp ridge. The outer slope is largely modified by gullying and basal sapping, but parts of the slope still show the original steep angle of rest of the scoria to be parallel to the ground surface.

7. *Flat bottomed or funnel shaped*

Cotton (1944, p. 255) wrote « the maars of the Eifel are funnels opened in a non-volcanic terrain and the explosions which opened them have expelled only small quantities of debris. These are maars in the strictest sense ». This is not strictly true, and it would be unfortunate if « maars in the strictest sense » implied a funnel shape. According to Frechen (1959) Gemundener and Pulvermaar are funnels with small flat-bottomed floors, but most of the bigger maars have a strikingly broad and flat bottom, not apparently due to alluvial fill. Bullenmerri and Gnotuk (S.E. Australia) were shown on published surveys (GRAYSON and MAHONEY, 1910) to have markedly flat bottoms to their steep-sided crater lakes.

The flat or funnel shape of the crater is significant in consideration of fluidisation in maar formation (see p. 59).

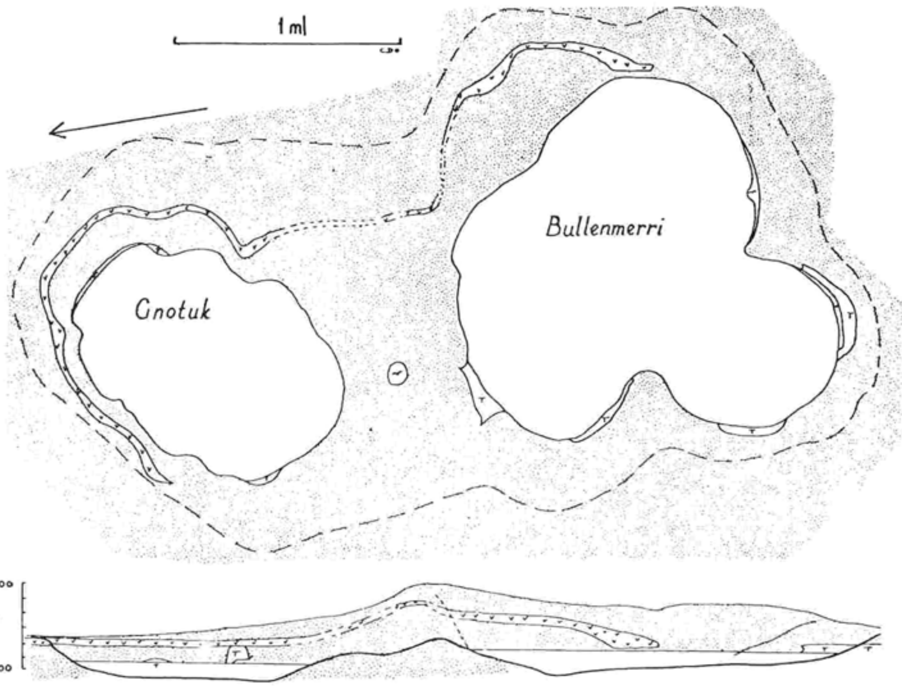

FIG. 3 - Gnotuk and Bullenmerri. Plan, section and orthogonal view of eastern side.

8. *Collapse or constructional features*

Simple volcanic explosion builds a ring around the vent made up mainly of outward dipping deposits, but with inward dipping layers within the crater (Fig. 2; see also COTTON, p. 262).

Some maars such as Purrumbete and Tower Hill (S.E. Australia) have retained the inward-dipping tuffs in parts of their rims, indicating their explosive origin. Most maars however, have no inward-dipping tuff, but since no process can be envisaged that would deposit *only* outward-dipping tuffs, it is presumed that the inner part of the rampart has fallen back into the crater. This seems a reasonable conjecture, and is supported by the observation that present day land-

FIG. 4 - Tower Hill. (*Photo by kind permission of Alex Wilkins of Warrnambool*).

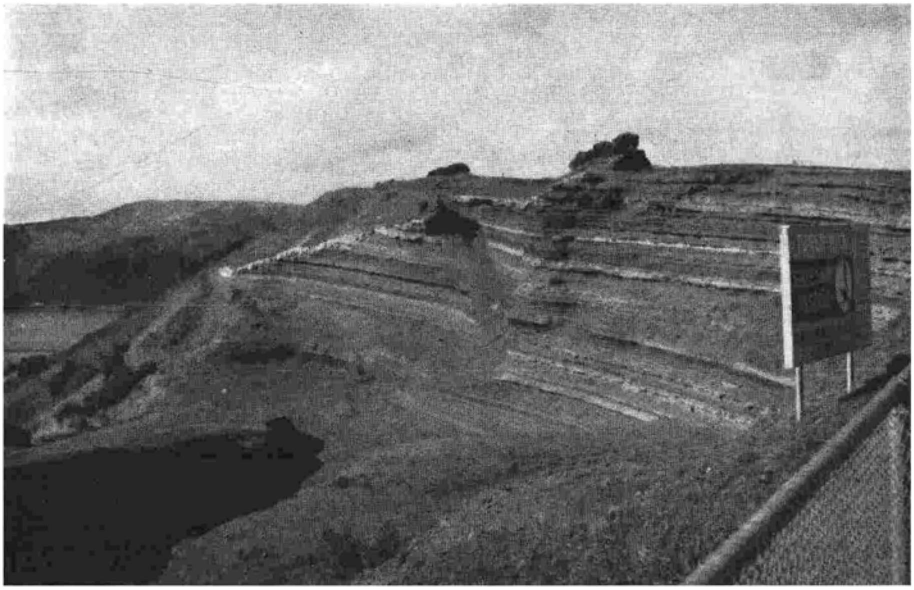

FIG. 5 - Bedded tuff, Tower Hill. (*Photo C. D. Ollier*).

sliding is prevalent on steep inner slopes of many maars. Some small landslides simulate faulting into the crater.

Most, if not all, calderas are formed by volcanic collapse (WILLIAMS, 1941). If collapse is important in maar formation, the problem arises of how maars differ from calderas, and the following distinction is proposed: Calderas are large craters (5 km and over), and are due to large-scale collapse; maars are smaller, are dominantly constructional features, and collapse plays only a minor part.

The distinction is made partly on genesis and partly on form. Since genesis can only be inferred, it is possible to confuse the larger maar with small calderas, and some volcanoes are therefore controversial. Mount Gambier (S.E. Australia) is regarded by WILLIAMS (1941) and FENNER (1921) as a group of calderas; Tower Hill, Mt. Leura and Mt. Warrnambool (S.E. Australia) are regarded as calderas by GILL (1950). These are all thought to be maars by OLLIER and JOYCE (1964).

Zuni salt lake has been attributed to collapse induced by the solution of underlying beds of salt and gypsum according to WILLIAMS (1941), but in view of its marked similarity to Tower Hill, Mt. Leura, and other nested maars of S.E. Australia, this seems very unlikely.

A further complication is presented by maars of the Meerfelder type which, although in many ways perfect, present a « space problem » in that the known ejecta is not equal in volume to the hole produced, some collapse consequently being inferred (see p. 71).

9. *Ejecta present or not*

Some « diatremes » or « gas maars » have no apparent ejecta; can they properly be regarded as a variety of maar? It seems impossible to make a hole without doing something to the material that formerly occupied the same space, and so unless the holes are completely due to collapse, the main difficulty must be in finding the debris. Such collapse might be caused by solution of subsurface limestone, in which case it is no relation to a maar. It is possible to envisage a transitional series from much ejecta — little ejecta — no detectable ejecta, and some diatremes *may* belong to the maar class though no ejecta can be found. But such a dubious classification must always be tentative, and it would be better to reserve the term maar for features more positively identified, and have another term

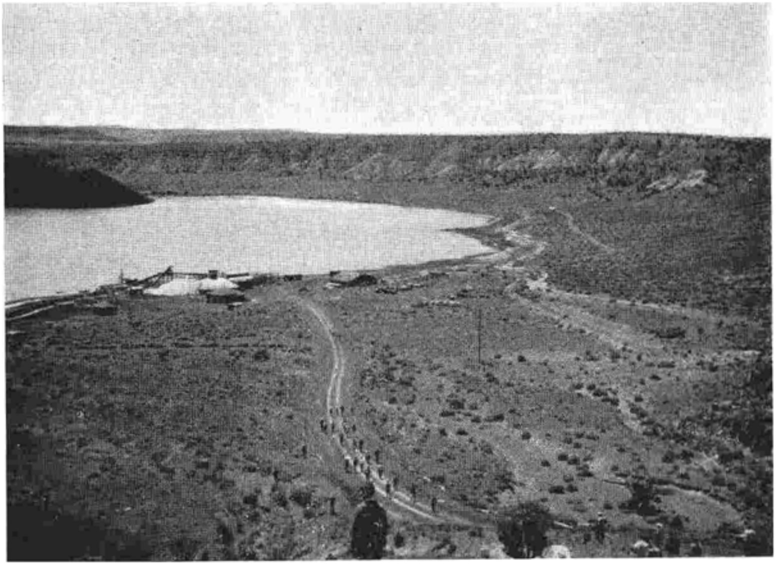

FIG. 6 - Zuni Salt Lake. General view of the floor and rampart. (*Photo C. D. Ollier*).

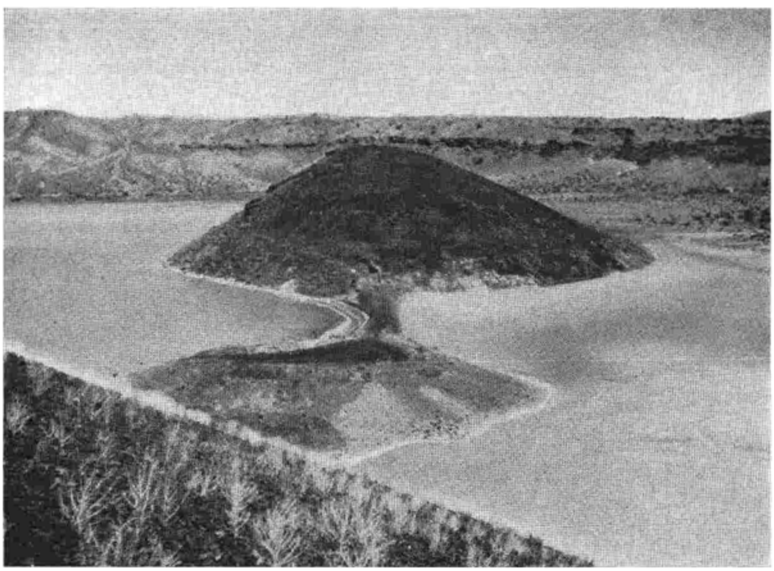

FIG. 7 - Zuni Salt Lake. The central scoria cones. (*Photo C. D. Ollier*).

for those craters that are only possibly of volcanic origin. In the Eifel such craters are known as Kesseltäler (cauldron valley).

10. *Country rock or pyroclastics in ejecta*

The nature of the ejecta does not seem to be diagnostic of maars, though it should obviously be a part of any description. Some maar rims consist very largely of country rock, such as Ulmenermaar (Eifel) which is of coarse Devonian shale fragments, and Mt. Gambier (S.E. Australia) which is largely made of Tertiary limestone, often coarse. Others are almost all pyroclastics, such as Purrumbete (S.E. Australia). Yet others have a mixture of pyroclastics and country rock, such as Wangoom (S.E. Australia). Most of the rim of Meerfelder (Eifel) is composed of bedrock, except for a thin cover of 5 m of tuff.

There is no perfect relationship between form and the nature of the ejecta, though coarse ejecta makes steeper cones than fine, and when country rock is dominant in ejecta it is often coarse (but in Pulvermaar there is finely divided shale). COTTON (1944) implies that « true maars » are built up chiefly of rock fragments derived from the immediately underlying terrain, but since this is not true even of many of the maars of the Eifel region it would appear that maars can be « true » whatever the nature of the ejecta.

Writing of Mt. Gambier (S.E. Australia), and following a statement by FENNER (1921), Howell WILLIAMS (1941) reasoned that « Since limestone blocks are nowhere to be found among the basaltic ejecta, the depressions cannot have been formed by explosion alone ». This statement is factually untrue, for there is a great deal of limestone in the ejecta, including large boulders. Williams reasoning, however, sounds plausible, and the surprising maars are those, such as Purrumbete (S.E. Australia) that are composed almost entirely of pyroclastics.

11. *Single or multiple eruptions*

Some writers give the impression that maars are due to single great explosive eruptions.

Many maars are indeed simple, but some are undoubtedly multiple. Hengstweilermaar (Eifel) is a dubious maar but sections show a buried soil and fossil trees within the ejecta, indicating a consid-

FIG. 8 - Pulvermaar. (*Photo C. D. Ollier*).

FIG. 9 - Meerfelder. (*Photo C. D. Ollier*).

erable pause between eruptions. At Bullenmerri (S.E. Australia) there are contorted tuffs overlain by a thick basalt flow and then more, horizontal tuffs, indicating at least two phases of tuff eruption. Some Eifel maars suggest an eruptive cycle of fine-coarse-fine ejecta. There are also numerous maars, such as Mt. Gambier (S.E. Australia) that have first a small lava flow, and then an explosive, maar-forming eruption.

Although many maars are single eruptions, perhaps taking place over only a few days, the definition of maars should not exclude multiple eruptions.

COTTON (1944, p. 254) wrote « It would appear that each volcanic maar has been the result of a very brief episode of activity, following which the « embryonic » or « abortive » volcano has shown no further signs of life ».

Rather more complex multiple eruptions are known, however, and require separate treatment. In some instances after the formation of a simple maar, continued or later activity builds a scoria mound or scoria cone on the same volcanic centre. Crater Hill (New Zealand), Tower Hill (S.E. Australia) and Zuni Salt Lake (U.S.A.) are examples of this. The appearance of the maar and scoria cones on the same eruptive centre is too great a coincidence to suppose anything other than successive eruptions from the same vent. A few maars also have associated flows of basalt lava, including Crater Hill (New Zealand) and Mount Gambier (S.E. Australia).

Other volcanic assemblages are complex for different reasons. Bullenmerri (S.E. Australia) is of clover leaf shape due to three eruptions from close but separate centres, which all seem to have erupted together. Staughton's Hill (S.E. Australia) has a maar, a scoria cone, and a small lava pit on close but separate sites. These close volcanic events may of course be entirely fortuitous, but it seems more probable that they are related.

12. *Catastrophic or quiet eruption*

Some authorities give the impression that maars are formed by extremely violent or catastrophic eruptions, which form low, wide craters rather than the steep and narrow craters of scoria cones. COTTON (1944, p. 263), for instance, writes that the difference between the tuff rings and scoria cones depends on the mode of ejection. Scoria mounds are due to fire fountains; tuff rings must have

FIG. 10 - Mount Gambier. Around Blue Lake on the left bedrock can be seen between the water and the overlying pyroclastics. (*Photo kindly supplied by the Town Clerk, Mount Gambier*).

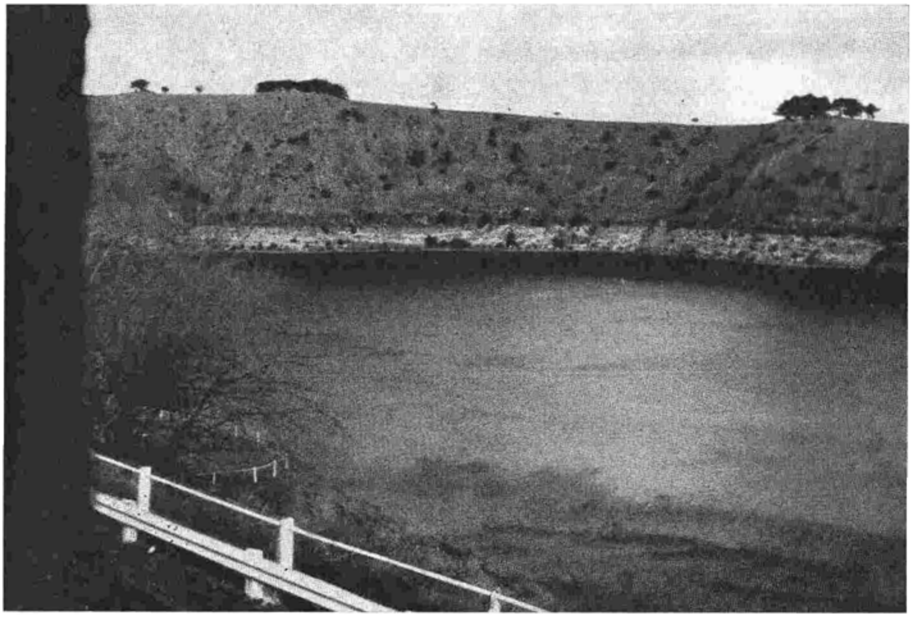

FIG. 11 - Blue Lake, Mount Gambier. (*Photo C. D. Ollier*).

resulted from more violent explosions which have scattered projectiles further afield. As far back as 1865, HUMBOLDT wrote of the Eifel maars, « The Maars, sunk in the Devonian slate, appear, as has already been observed, like the craters of mines, into which, after the violent explosion of hot gasses and vapours, the looser ejected masses (Rapilli) have for the most part fallen back ». Humboldt also wrote « In the volcanoes of the Eifel we must carefully distinguish from each other two kinds of volcanic activity of very unequal age

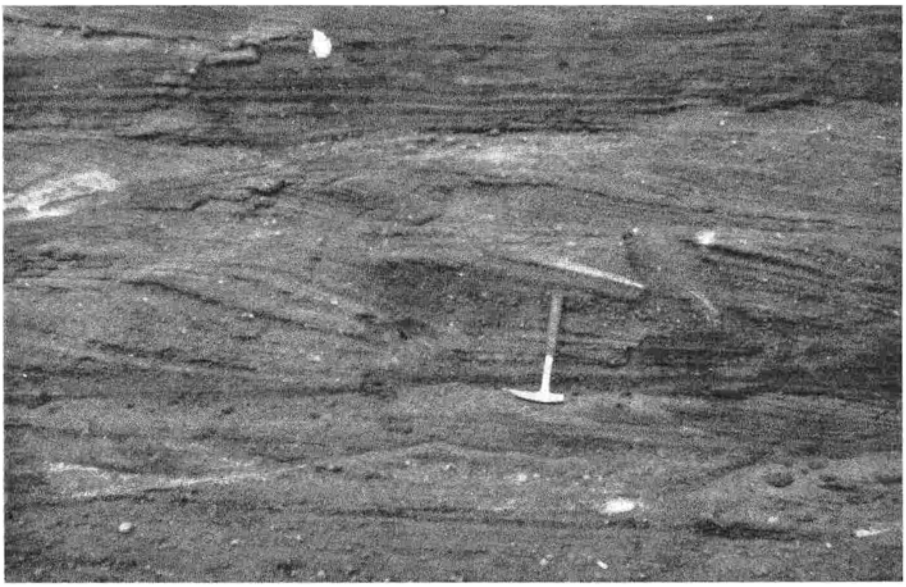

FIG. 12 - Cross-bedded tuff, Purrumbete. (*Photo C. D. Ollier*).

— the true volcanoes emitting streams of lava; and the weaker eruptive phenomena of the Maars ». This is the only reference that attributes maars to *weaker* eruptive phenomena, and, presumably, in view of the earlier statement, this merely means that the eruption did not produce much lava. RITTMANN (1962, p. 115) has a diagram in which viscosity of magma is plotted against quantity of magma produced, and related to the degree of violence in explosive activity. High explosiveness with little or no production of lava is shown to give rise to gas maars (diametres); with slightly more fluidity maars with a thin covering of pyroclastics are produced; and with the same degree of explosiveness but with a greater quantity of lava, maars with pyroclastic ring-walls (ramparts) are said to be produced. A really catastrophic eruption would produce a mass of ill sorted ejecta. In fact many maars show very good bedding and even graded bedding and cross bedding (Figs. 5 and 12). The beds do not necessarily indicate separate eruptions, but they at least indicate phases of greater and less violence within an eruption, and eruptions sufficiently quiet or gentle to be influenced by wind, which gives rise to the cross bedding and also causes greater accumulation of ejecta on the downwind side of the maar. The violence of volcanic eruption therefore seems rather variable in maars, and should not be used in the definition.

13. *Phreatic eruption or not*

A very frequent suggestion in connection with maars is that they are formed by phreatic explosion due to the violent reaction of ascending magma and groundwater. Cotton (1944, p. 257) for instance, wrote « ...most if not all true maars have been regarded by many geologists as the products of « phreatic » explosions... such as may occur when... ascending magma encounters water near the surface ».

We have already seen that catastrophic violence is not necessary to form maars.

In some areas the phreatic idea is nevertheless feasible. In S.E. Australia, for instance, maars usually occur over porous limestone, which would have provided ideal conditions for phreatic explosions. In the Auckland (New Zealand) field simple explosion craters are commoner in low-lying areas — particularly where thay are formed in water-logged Pleistocene silts — than in more elevated districts. Diamond Head and similar forms in Hawaii could have been formed by magma-water contact either in the open sea or in a cavernous coral reef. It is certainly a striking fact that all the tuff-rimmed craters lie along the coast and all the cinder cones lie inland.

Stearns (1926) described the vulcanicity of the Mud Lake area, Idaho, where there are five tuff rings, possibly maars, known as the Menan Buttes. The largest has a crater half a mile across. These cones are on the gravel fan of Snake River which is saturated with ground water. Elsewhere in the region, where ground-water was negligible, quiet fissure eruptions occurred.

However, in the type area of the Eifel the maars are on a plateau of Devonian shale, which would be very unfavourable for phreatic explosions, and some modern workers in the area are not at all in favour of the phreatic hypothesis (H. NOLL, personal communication, 1966). It is remarkable how entrenched the idea of phreatic eruption has become, considering the very poor support it receives in the Eifel region. Other regions where the phreatic idea seems improbable are Tritriva (Madagascar) and the Rubirizi volcanics (Uganda). The latter are however very instructive for they were erupted through the Pre-Cambrian rocks east of the Rift Valley wall, while the nearby Katwe volcanoes were erupted through the Rift Valley sediments which were probably saturated with ground water. There is indeed a difference in form between the two sets of volcanoes, and the wider and more perfectly circular maars of the Rift Valley floor may be attributed to reaction with groundwater, that is phreatic explosions. However, some irregularity of the other maars might be simply due to their eruption on an irregular rather than a flat ground surface. As it may be doubted whether phreatic eruption is important or even necessary in maar formation, it should not be an essential feature in their definition, or in the separation of « true maars ».

14. *Fluidisation mechanism involved or not*

HOLMES (1965, p. 313) divides ring craters into explosion vents and fluidisation craters.

Explosion vents are said to give rise to generally small funnel-shaped craters with flaring sides, and the pyroclastics include a high proportion of coarse angular material.

Fluidisation craters on the other hand are said to have wide shallow craters with nearly flat floors, and low rims that slope gently outwards to thin deposits of ash spread widely over the surrounding countryside.

It would seem that the explosion vents of Holmes correspond to what are called Gemundener sub-type maars in this paper (see p. 68) and the fluidisation crater to what are here called Wangoom sub-type maars. The example of fluidisation craters given by Holmes are the volcanoes of the Rift Valley near Ruwenzori, though as pointed out above there are differences of form within these volcanoes.

If Holmes' distinction is valid, the distinguishing features appear to be distinctive type of pyroclastics, and a notably flat floor. Holmes writes of the pyroclastics — « Most of the pyroclastic material is excessively fine, and invariably so at the base of the deposit, while the larger fragments are so well rounded that they have often been misleadingly described as bombs. Fresh tephra is generally represented by minute lapilli of approximately spherical form, and these tend to be uniformly mixed with debris from the perforated rocks ». He later writes, « The flat floors of the craters which may be up to two miles across, their well-mixed materials, and the local occurrence of outcrops of the neighbouring country rocks veined with tuffite, all suggest that during the eruptions the materials of the floor were in the state known in industry as the « expanded » or « Boiling » bed. No process is known other than this stage of fluidisation which could ensure so smooth a floor ».

It has already been seen that the floors of maars in general show considerable variation, and it is not yet certain that all the flat floored maars show the other features that Holmes says indicate fluidisation. Humboldt's early suggestion that the « looser ejected masses (rapilli) have for the most part fallen back » could also account for flattish floors.

15. *Petrology and maars*

Maars erupt basaltic lava. RITTMANN (1962, p. 115) has a table in which maars are shown as related to acid, viscous magma, but this is not so, and all the examples mentioned in this paper are of basic magma. Acid and intermediate volcanics give rise more often to simple cones or calderas.

Definitions and Statements About Maars

Having reviewed the criteria involved, various definitions of « maar » may now be considered. In fairness to previous authors it must be realized that some of the statements that follow were not offered as formal definitions, but merely presented in general discussion. Nevertheless, a consideration of the ideas contained in the statements helps to understand how modern concepts of what constitutes a maar have evolved.

DAUBENY, 1826, p. 46

> Scattered however over the greater part of the district alluded to [the Eifel] are a number of little conical eminences, often with craters, the bottoms of which are usually sunk much below the present level, and have thereby in many cases received the drainage of the surrounding country, thus forming a series of lakes, known by the name of « Maars », which are remarkably distinguished from those elsewhere seen by their circular form, and by the absence of any apparent outlet for their waters.

This early definition uses « maar » for the lake rather than the landform. The « conical eminences » gives a rather false impression of the relief associated with maars.

HUMBOLDT, 1865, p. 231

> Maars are cauldron-like depression in non-volcanic rock, formed by themselves.
> The Maars sunk in the Devonian slate appear, as has already been observed, like the craters of mines, into which, after the violent explosion of hot gasses and vapours, the looser ejected masses (Rapilli) have for the most part fallen back.

The first statement is admirably simple, though a reference to the deposits around the rim would make it more complete. Some maars may be erupted through older volcanic rock — the non-volcanic rock beneath is extremely common but not essential. The simple explanation of the fall back of erupted material accounts for the flat bottoms of many maars.

SCHNEIDER, 1911, p. 86

> These have usually been called diatremes. In typical form they are of elliptical cross-section and penetrate the older formations without having built up cones at the surface. These volcanic tubes are not rare since Tertiary times and are of several types, depending upon the form of eruption.

Although it would be an exaggeration to say that maars are strictly circular, « elliptical » gives a wrong impression for many are impressively round. Lack of cones at the surface would exclude the Zuni type (see p. 68). The use of the term « volcanic tubes » suggests that maars are related to volcanic necks, but there is no doubt that they are due to explosion at the surface and considerably wider that the associated neck.

DALY, 1914, p. 144, quoted in « *Glossary of Geology* », 1957

> Maars are relatively flat-floored explosion craters at vents which are either coneless or else provided with inconspicuous cones.

Maars can be funnel-shaped and in the Zuni type (p. 68) can have conspicuous cones.

COTTON, 1944, p. 254

> Maars and tuff rings: Forms that are ring-enclosed craters rather than elevations of the land surface — or may even be mere bowl-shaped hollows without raised rims — result generally from sporadic explosions, occurring either singly or in a brief series, followed by complete cessation of activity.

This definition would exclude Zuni type volcanoes, but otherwise seems sound, and uncomplicated by details that are not always present.

COTTON, 1944, p. 254 also writes:

> A hollow, excavated by a volcanic explosion provides a natural well if deep enough to intersect the water table. Such a hollow, when occupied by a lake, becomes a rather conspicuous landscape feature. It is termed a « maar », the name being taken from examples in the Eifel district of Germany.

By stressing the importance of the presence of a lake this is a poorer definition of maar than the preceding statement.

HILLS, 1951, p. 177

> When a new volcano is born, a fissure or a roughly cylindrical pipe is formed in the Earth's crust. The adjacent rocks are

> shattered, and are sometimes thrown out by gaseous explosions in the form of a low ring round the volcanic centre. Some volcanoes never grow beyond this stage, and others merely throw up a low ring of scoriae or tuff without emitting molten rock. The craters of such volcanoes are funnel-shaped holes which have been blown out of the upper part of the crust. They are termed *maars.*

Although presented discursively rather than as a definition this statement is substantially correct. Some maars do have associated lava flows, some are flatbottomed and the term should refer to the rim as well as the crater.

THORNBURY, 1954, p. 501

> In the Eifel district of Germany, there are numerous lakes called maare or maars which occupy craters that seem to have been formed by volcanic activity that ended without the building of cones.

This definition uses maar for the lake rather than the crater. It excludes the Zuni type (p. 68), and also the Noorat (Ubehebe) type (p. 69). Thornbury appears to support COTTON's separation of the latter when he writes:

> Expulsion of volcanic ash, lapilli, and other forms of ejecta may build a ring about a volcanic vent and produce a crater. COTTON (1944) called craters of such origin *ubehebes.*

COTTON, 1944, p. 258, seems to equate dry maars with the Ubehebe or Noorat type of volcano.

> As example of volcanoes that are little more than embryos — dry maars, or « ubehebes », as they might be called — the two Ubehebe Craters in Death Valley, California, may be cited.

This suggestion does not seem to be warranted, for there are many dry maars of Pulvermaar (p. 67) and other types.

Glossary of Geology and Related Sciences, 1957, p. 175.

> A relatively shallow, flat-floored explosion crater the walls of which consist largely or entirely of loose fragments of the coun-

try rock, and only partly of essential, magmatic ejecta. Maars are apparently the result of a single violent volcanic explosion, probably of phreatic origin. Where they intersect the water table they are usually filled with water and form natural lakes. The term was originally applied to craters of this nature in the Eifel district of Germany.

Shallowness and flatness of floor are not good criteria, and many maars consist largely of igneous pyroclastic rocks. The explosion may be multiple, and not necessarily phreatic. Very few maars of the Eifel or elsewhere could meet all the requirements of this rather exacting definition.

STAMP, 1961, p. 303, gives two quotations and a comment by way of definition.

Maar (German) LOBECK, 1938, p. 683. The Eifel region of western Germany contains a number of low craters called *maars*, often lake filled.

FISCHER, 1950, p. 34. Explosion pit.

Comment — The term seems originally to have referred to a crater lake, but has sometimes been transferred to the crater itself.

« Low crater » presumably means low-rimmed crater or shallow crater, though some are funnel shaped and fairly deep. The comment could go further, for the term now often refers to the lake (if present), the crater and the ring of deposits around it.

EMMONS et al., 1960, p. 88.

At certain places, which may be distant from volcanic areas, low ridges occur around craterlike pits. The material in a given ridge consists largely of fragments of the country rock, but minor amounts of volcanic debris may be present. These structures are interpreted as embryonic volcanoes, in which the volcanic activity has been limited to the opening of a vent through the country rock. Such explosion pits are common west of the Rhine River in the part of Germany known as the volcanic Eifel. Since many of these pits, wich range from ¼ to ½ mile in diameter, are filled with water, they are called moors, or maars.

The lowness of the rims is relative. Volcanic debris may sometimes make up the major part of the material in the rims. It is not clear why because some are filled with water they should be called maars, and still less moors.

RITTMANN, 1962, p. 142.

Pumice ramparts or ring-walls, with wide craters, owe their origin to powerfully explosive pumice eruptions and pass laterally into sheets of pumice and ash... Ground water then seeps into the widened but still unfilled crater to form a crater lake or Maar. p. 45. If the gas explosions were very powerful, pumice and ashes would have been widely distributed over the neighbourhood and would form only a thin layer, the volcano then consisting essentially of an explosion funnel, or diatreme. Such diatremes are frequently filled with ground-water and become Maare.

These two statements are more concerned with the explosive activity than with the definition of the landform, but it would seem that Rittmann would use the term explosion funnel as equivalent to diatreme, have separate terms for the rim (pumice ramparts or ring walls) and would use maar only for the crater when water filled.

Dictionary of Geological Terms, 1962, p. 300.

Maar. A crater formed by violent explosion not accompanied by igneous extrusion, commonly occupied by a small circular lake.

This definition would exclude the Zuni-type of volcano (p. 68) and possibly all maars with igneous rock in the pyroclastics.

HOLMES, 1965, p. 314.

Where the floor of a ring-crater is deep enough to fall below the ground-water level of the district it becomes the site of a shallow lake, which is then able to defy evaporation, as in Uganda (fig. 222). In the Eifel volcanic district a ring-crater occupied by a lake is called a maar (fig. 223).

This definition is somewhat indefinite, but does include the ring, the crater and the lake. No allowance is made for dry maars, for the lake need not be present. Holmes' fig. 223 is of the Lachersee, which is too large and too complex to be regarded as a maar by many authorities.

This review has shown that there is no adequate definition of maar available, and indeed it is possible that the landform is so controversial that no definition acceptable to all workers is possible.

Nevertheless the term covers a group of features that have much in common, and would benefit from having a single connotation.

A further advantage of having a name for this group is that it enables the classification of negative volcanic landforms into three types: craters in volcanic cones; maar craters; and caldera depressions.

If the group called maars is considered a useful subdivision of volcanic landforms, it may be asked if the word « maar » could be replaced by a simpler term or phrase. The present review of definitions and descriptions has not produced any satisfactory alternative. « Explosion crater » is about the best alternative, but the craters of other kinds of volcanoes can be regarded as caused by explosive eruptions of magma, and even bomb craters would come under such a general heading. It seems therefore that if the term « maar » did not exist a word would need to be invented, but since the term is available it is best to use it, and try to define it in the most useful way.

The wide range of variation amongst landforms recognised as maars means that any acceptable definition must be as general as possible so as not to exclude too many variants, and yet the definition must be specific enough to exclude other volcanic landforms such as scoria cones and calderas. In order to give a definition of the whole class without sacrificing the details of variation within the class, a general definition is proposed, together with subdivision by means of « type » examples.

A Proposed Definition of « Maar »

Maars are landforms caused by volcanic explosion, and consist of a crater, which reaches or extends below general ground level and is considerably wider than deep, and a surrounding rim constructed of material ejected from the crater.

Considerable variation is possible within this definition, and since « maar » covers a family of related landforms, subdivision is required.

When enough maars have been described in sufficient detail it may be possible to arrive at a classification by the methods of numerical taxonomy. In the meantime any number of classifications

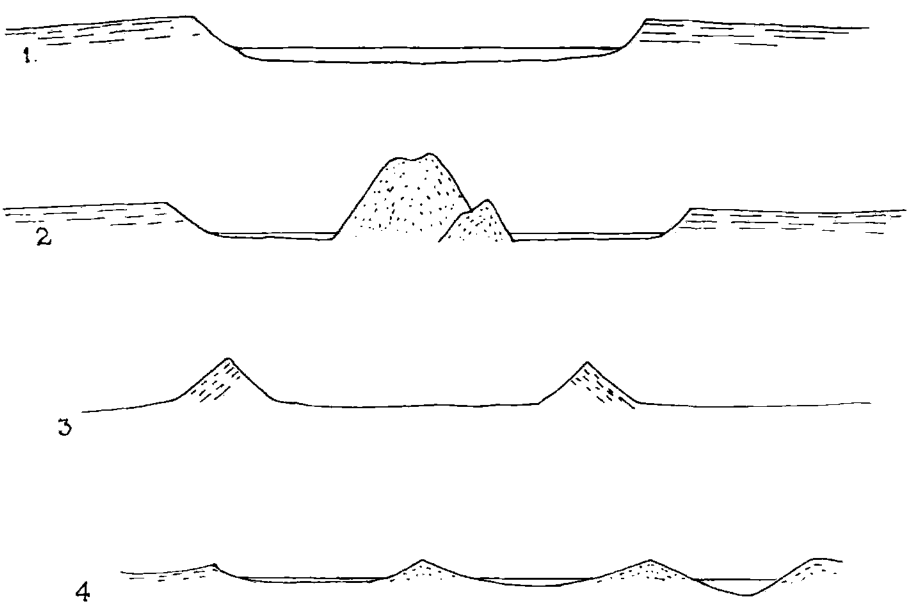

Fig. 13 - Types of maars. 1. Pulvermaar - 2. Zuni - 3. Koki - 4. Red Rock.

could be set up, depending on the status given to different properties of the maars. Rather than set up a theoretical classification system, the maars can be subdivided by means of approximation to a « type maar », rather in the manner that Cotton (1944) distinguished « Ubehebes » as a group.

Some suggested types are given below. They are based as far as possible on form and material, as genetic considerations are often dubious.

1. *Pulvermaar.*

The simplest and most general type of maar is exemplified by Pulvermaar in the Eifel, and so its name is chosen for the group.

Purrumbete, and Keilambete are examples from S.E. Australia; Pukaki lagoon is one of the simplest New Zealand maars, and SEARLE (1964) gives other examples; the Katwe maars of Uganda are also of this type.

If desired this group of simple maars could be divided into subgroups on various criteria. The list below shows some possible divisions, with examples.

Keilambete	Low and wide rim
Tritriva	High and steep rim
Ulmenermaar	Dominantly country rock in rim
Purrumbete	Dominantly igneous pyroclastics in rim (tuff ring)
Wangoom	Flat floored
Gemundenermaar	Funnel shaped crater

2. *Zuni.*

This signifies what might be termed a nested maar, and is named after Zuni Salt Lake, U.S.A., which is a maar with scoria cones on the same centre of eruption.

SEARLE (1964) described a sequence of Zuni type maars from the Auckland area. Mangere lagoon has a scoria cone built only a few feet above the mudfilled floor of the crater; Waitomokia has three little scoria cones about 70 feet high; Mount Richmond has a scoria mound big enough to overtop the tuff ring in parts; Mount Wellington has a tuff ring almost completely buried by the scoria cone. In S.E. Australia examples of Zuni type maars are Tower Hill, Mount Leura, and Mount Warrnambool.

3. *Koko.*

Koko crater and Diamond Head are two Hawaiian volcanoes distinguished by having steep inner and outer walls, and hence sharp crests on their rims. Although the outer slope is modified by gully erosion and basal sapping, the steep slope was originally parallel to the angle of rest of the lapilli. STEARNS (1935) calls this type of landform a tuff cone, but as it has a wide crater and is attributed to violent (phreatic) explosion, it can reasonably be regarded as a variety of maar.

4. *Red Rock.*

If maars (or Noorat type scoria cones, see below) are so closely spaced that they intersect, the typical circular form cannot be de-

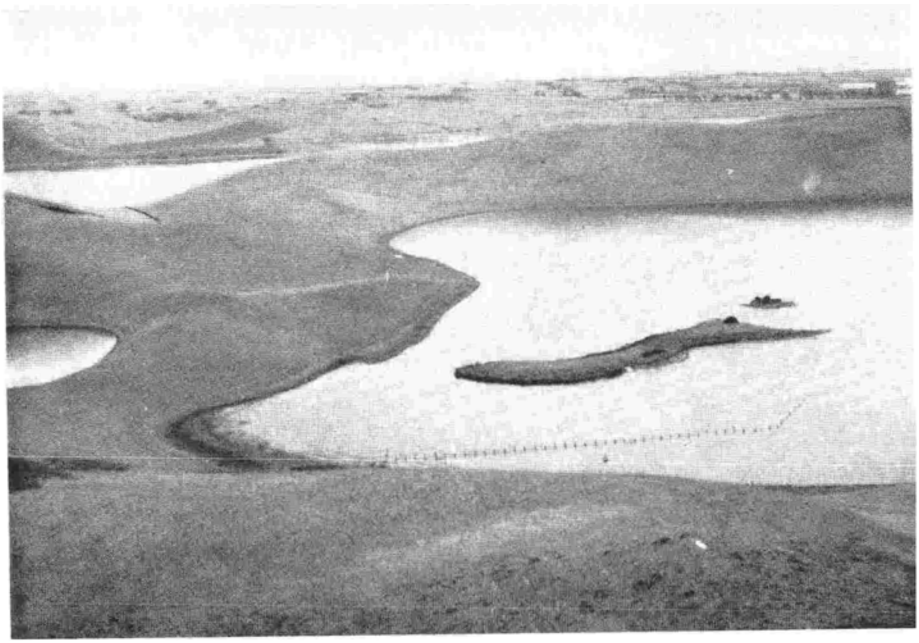

FIG. 14 - Red Rock. (*Photo C. D. Ollier*).

veloped. Red Rock (Victoria, Australia) which has 7 craters, 5 broad lakes and rims up to 300 ft. above lake level, may be taken as the type for such closely spaced multiple eruption volcanoes.

Other Type Volcanoes

Noorat

With increasing steepness of the rim, and reduction of the diameter of the base, a maar could conceivably be linked through a series of intermediate types to a scoria cone (Fig. 15). A scoria cone with a deep, funnel shaped crater that may contain a lake may be given a special name to distinguish it from the common type of scoria cone in which the crater is less significant. The Ubehebe craters of Death Valley, California, are of this type, but the name has been used as a type name by COTTON (1944, p. 258) with a number of other implications. He writes that they are « little more than embryos — dry maars... ». Dry maar has been used in other connections, especially to the Barbato or Kesseltäler type. The actual Ubehebe craters are indeed dry, but are in a desert and playa deposits are present at the bottom of the craters. He also writes « (Ubehebes)... have been built

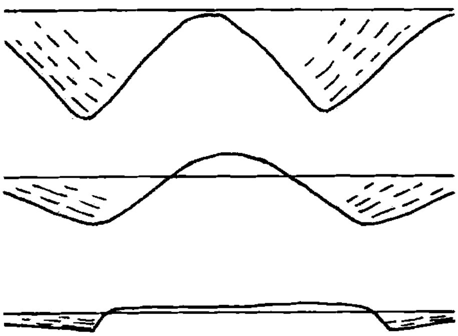

FIG. 15 - Diagram to show the continuous series from maar to Noorat type volcanoes.

up chiefly (as is the case with true maars) of rock fragments derived from the immediately underlying terrain » but VON ENGELN (1932) clearly states that they are built mainly of finely bedded basaltic tuff, and fragments of country rock are incidental.

The largest Ubehebe crater is 500 feet deep. As the name « Ubehebe » is pre-empted, the name « Noorat » is proposed, from Mt. Noorat, Victoria, Australia, which is 600 ft. high and has a crater 600 ft. deep.

It should be stressed that a Noorat is not a type of maar but a type of scoria cone, that may be linked through a continuous series of intermediate forms to a maar.

Barbato

In the Eifel there are maar-shaped depressions about which there is no ejecta that can be related to the depression. Their origin is therefore unclear, and they are known as Kesseltäler (Cauldron valleys). Similar ones are Lake Correo, Fossa del Ballerino and Fossa Barbato north of Naples, Italy. This type has also been called a diatreme, and is equivalent to the gas maar of RITTMANN (1962, p. 115). Some so-called crypto-volcanic features may be of this type too. Since real examples are being used as type maars, the name Barbato is suggested, though Kesseltäler, in general usage for such features in the Eifel, is in some ways preferable.

Meerfelder

Meerfelder is the largest maar in the Eifel and is thought to be due partially to collapse, because the ejecta do not equal the crater in volume. It might therefore be an intermediate type between a caldera due to collapse and a maar due to explosion. However in a great many maars a space problem is possibly present. Meerfelder is the only maar in this category, and since it could be classified with the Pulvermaar group were the volume problem disregarded, it is doubtful if a new class of maars is required to deal with it.

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FIG. 16 - Wangoom. (*Photo C. D. Ollier*).

M. SCHWARZBACH and H. NOLL showed me the Eifel volcanics and Prof. G. IMBÒ, P. GASPARINI and A. RAPOLLA showed me the maars

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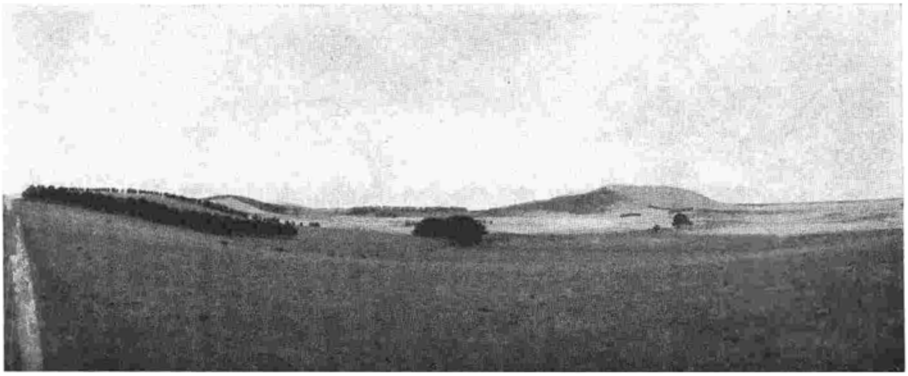

FIG. 17 - Mount Warrnambool. (*Photo C. D. Ollier*).

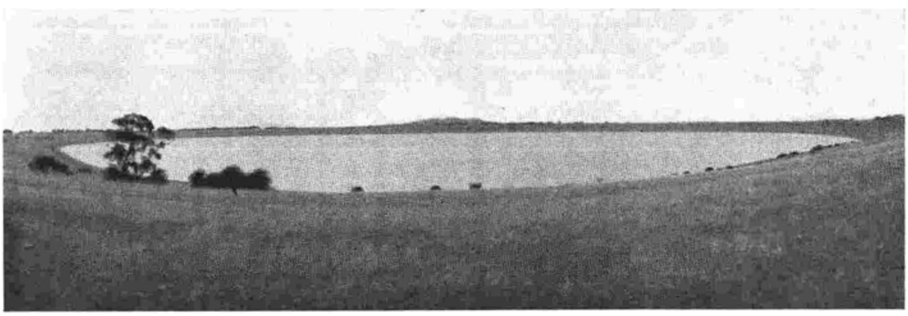

FIG. 18 - Keilambete. (*Photo C. D. Ollier*).

maars very freely, and contributed much to the content and ideas presented in this paper. I remain responsible for any errors of fact or interpretation.

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