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An economical volcanic prediction technique by Gresham Clacy

PROLOGUE

It is with interest that, with time, what to predict of oncoming Volcanic Eruptions has not changed. This comes from Jaggers' early paper on Volcanic tremor. To predict is to know in advance, to inform the danger to people who live within its confines. Charts can be made of past eruptions, and from the dates a ball park figure is derived. This is a very hit and miss method. It is very important to have an ongoing seismic study relevant to that volcano, especially where lives and property are at stake.

We know from the past that earthquakes and volcanoes have caused some of the world's worst disasters. Predicting earthquakes is very difficult because there is, to date, no reliable preceding information, apart from stress build-up along a fault. To try to predict when the fault is suddenly going to slip is being worked on. An earthquake affects destructively large areas, unlike a volcano, which is confined to a smaller area usually around the volcano itself. In a lot of cases, especially when the location of volcano is the sum total of a single island, the information of an impending eruption is very important with very little space for manoeuvre for the population to escape its ferocity.

However! a volcano has a preceding build-up of flowing magmas underground. This has its own seismic signature and, because of the seismically noisy nature of the magmas which produce the eruptions, they can be monitored, or detected, on the surface using seismometers.

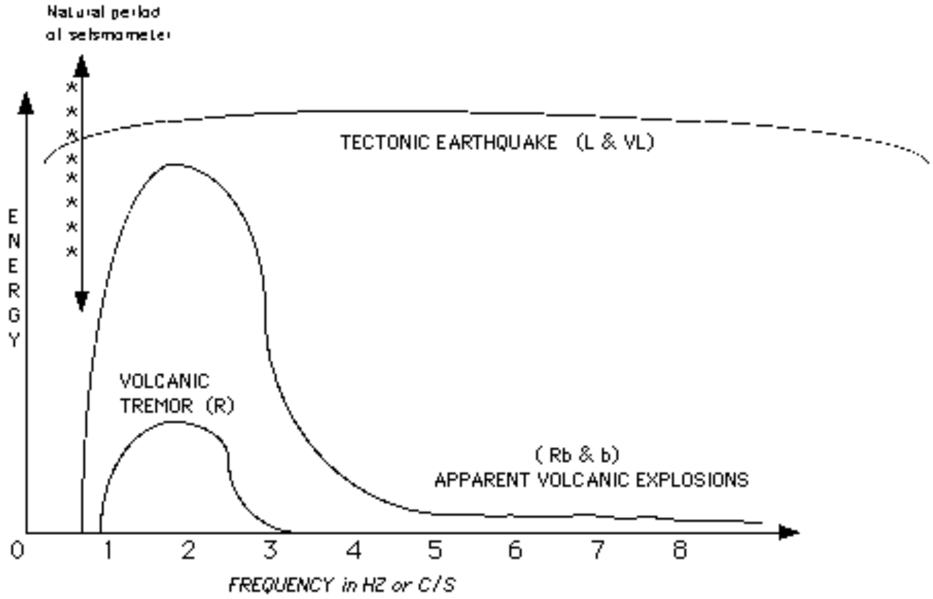
Whereas earthquakes of most sizes can be monitored worldwide using long period seismic equipment, unfortunately volcanic vibrations are in the short period regime. So they need to be monitored on a local basis because they are not as powerful in amplitude as large earthquakes.

The development of the listening technique has a twofold advantage: The first is speed of analysis with on the spot continuing seismic signals, when the activity is occurring - see paper reprinted at the end of this article entitled:-
"Analysis of Seismic Events Recorded with a Slow Motion Tape Recorder near Chateau Tongariro New Zealand during February 18, 1966 to December 31, 1966".
(Appendix 2).
The second is isolating geothermal areas, which are motivated by magmas rising to the surface but being forestalled by a body of water for producing steam, published in paper by the author, using the same portable equipment as for this prediction technic. It is reprinted at the end of this article entitled:-
Geothermal Ground Noise Amplitude and Frequency Spectra in the New Zealand Volcanic Region"
Published In The American Geophysical Union's 'Journal of Geophysical Research Vol.73 August 15, 1968, No 16, P. 5377 to 5383'. (Appendix 4).

Chapter I: IN SEARCH OF VOLCANIC NOISES

What is there about volcanism that lends itself to seismic monitoring? Magmas appear to produce noises within the seismic frequency boundaries which are readily detectable by seismometers on the surface and surrounding area of a volcano.

This question is best answered by understanding that magmas are the prime motivator of volcanism. These migrate underground and, in so doing, contact many highly variable materials including minerals, rocks, fluids, gases, etc. It is the highly variable nature and mixture of these elements that seems to give minor- to great variations of activity, which add to the basic seismic frequencies and amplitudes of magmatic tremor (fig. 1). See a list of types in Appendix 1.



A comparison of the average frequency spectra that can be expected from some volcanic events.

FIG 1

The main mechanisms causing these variations are probably from magmatic rejection. The immensity of scale that can be involved with these emanations can only be judged, at the moment, by the devastating volcanic eruptions of the past. Krakatoa is known to have fissures that occasionally open below sea level, so the sudden inflow of water upon the intruding magma could produce the kind of violent explosion experienced during the catastrophic event in the late 1800. A British submarine, plying around Krakatoa through the Sunda Straits during World War II, reported that, on several of its trips whilst passing Krakatoa, it had to turn off its sonar equipment because of the low frequency noises issuing from the base of the volcano. It also saved itself from the Japanese by sitting close to this sonar noisy patch; the Japanese sonar detectors could not distinguish between the noises emitted by the volcano and the submarine. The Japanese then depth charged the noise source believing it to be the enemy submarine, which slipped away to safety, leaving the Japanese well occupied with a naturally occurring target.

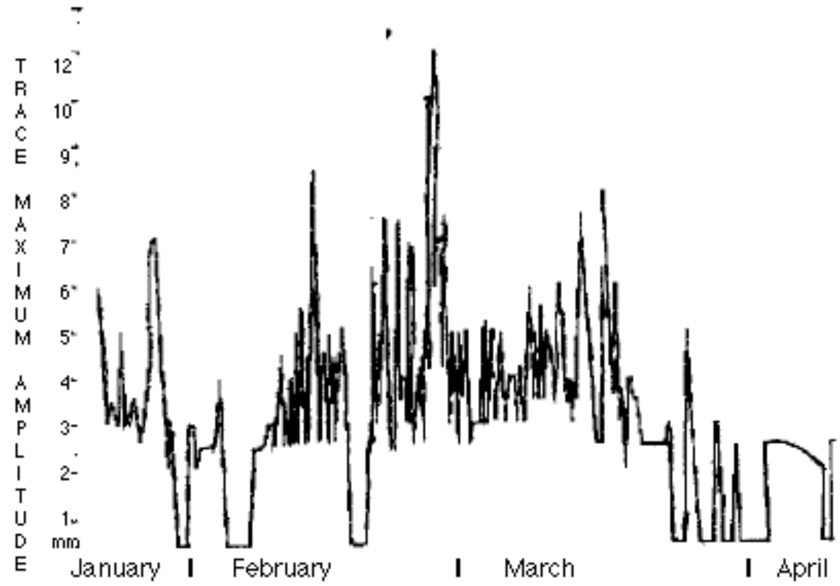
Jaggers of Hawaii, during the late l800's, identified volcanic tremor and stated that sometimes there were continuous tremors lasting many days, or very short bursts of tremor lasting minutes. Jaggers separated the actual frequencies and showed both periods of pure volcanic tremor (harmonious or fundamental) and periods of mixed frequencies (harmonics). He also demonstrated that these tremors preceded eruptions from craters and he referred to these tremors as magma migrations.

Salvatore Cucuzza-Silvestri, in his paper "L'eruzione dell' Etna del 1947", plotted subterranean emanations and durations of surface activity, whereas Takeshi Minakami discusses explosions and earthquakes and correlated earthquake plots.

S. Gorshkov made energy plots of earthquakes. The eruption concerned was gigantic, on the volcano Bezymianny. He also compared surface explosions recorded on a barogram at Kliuchi meteorological station and recorded seiches, changes in air humidity and magmatic volcanic tremor, which frequency = 1Hz and ground motion 1 micron being spasmodic. He also noted that its frequency decreased to 0.90 Hz and ground motion to 1.5 to 1.8 microns prior to the large visible explosion, after which there was no tremor recordable.

Gudmundar Palamason made available data collected from Seismic recordings during the 1964 Surtsey eruption. These lists contained references to volcanic tremor, apparent explosions and earthquakes. The author made a plot of the volcanic tremor data (fig. 2). This showed correlations with fire fountaining, followed by a quiet seismic period and a large lava flow. This information showed the best correlations recorded during the birth of this new volcanic island located South West of Iceland.

W.T. Kinoshita, of the Hawaii Volcano Observatory, stated that volcanic tremor is continuous ground movement caused by magmatic motion beneath the surface of the ground. The study of volcanic tremor is therefore one of the most powerful tools for a better understanding of volcanic manifestations and the location of magma, both in transit and in a reservoir underground: the most important factor in the prediction of volcanic eruptions.



Surtsey Eruption 1964. Plots of Volcanic Tremor intensity derived from a paper by: Hlvner Sigtrvasson and Eirikur Sigurdsonn.

FIG *2*

We see, from these papers and my own experiences, that Magmas are the most dominant driving force of active Volcanism. Because of this fact the most important primary thing to record, if one wishes to be made aware of an oncoming eruption, is volcanic tremor. Volcanic tremor can only be recorded in a reliable way by short period seismometers, on the flanks of the volcano under study.

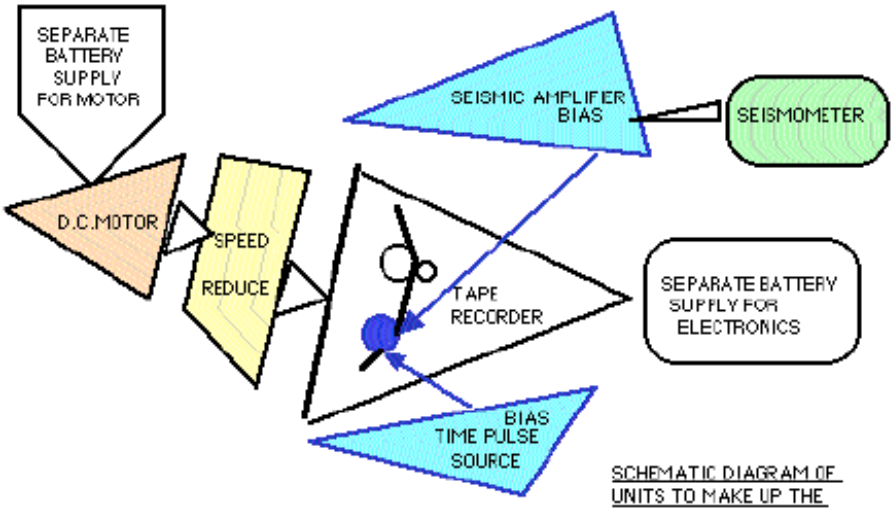
The only realistic chance of following the progress of magma to the surface, or crater, is by recording this manifestation by seismic means.

The next chapter describes a simple and low-cost method to achieve this and to get the results almost immediately.

Chapter II: A SlMPLE TAPE RECORDER & SEISMOMETER TO DETECT SEISMIC VOLCANIC SUBTERRANEAN EVENTS.

The best piece of geophysical field equipment is probably the simplest one, mainly because of its exposure to the elements, and also the exposure of the operator. An operator should be able to install the equipment quickly, check it quickly, and be on his way. It is amazing how rarely ideal field conditions occur when careful adjustments in the field to a piece of over-sophisticated equipment have to be made! Here in the field, Murphy's Law is a reality, and it is with these things in mind that the equipment chosen in this chapter will be of the simplest type, both to build and to operate. A greater degree of sophistication can be chosen and utilised, as will be seen by the technically minded.

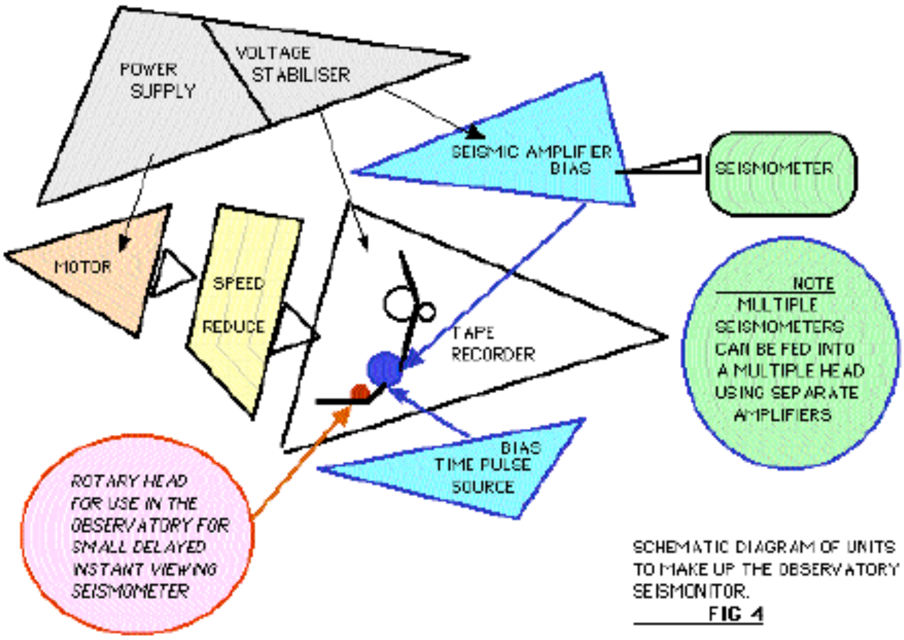
The first recorder is a portable AM or direct record type. This gives us the widest dynamic range, upwards of 100DB with a direct listening ability from an ordinary tape recorder in the field as well as at base. Component parts as in (fig.3). This type of recorder is the simplest and most effective way of checking a site or running as



SCHEMATIC DIAGRAM OF UNITS TO MAKE UP THE PORTABLE SEISMONITOR.

FIG 3

permanent station that will require servicing from time to time. It is especially useful in extreme hot or cold conditions with insulation or burying. It also has a very small electric current drain and only requires 160 mA of current at 12 volts DC. Two separate batteries are best as this prevents any interference from the motor.
The second model is basically the same but, being at an observatory, can utilise the mains power. Its layout is depicted in (fig. 4). It can have a greater number of in-line recording heads.



SCHEMATIC DIAGRAM OF UNITS TO MAKE UP THE OBSERVATORY SEISMONITOR.
FIG 4

Both models require a reel to reel type tape deck. This can be either reel to reel or a cassette recorder, stripped of its electronics and modified to take a gear reduction, (which is available from P.I.C.) to attain a capstan speed of 0.4 mm/sec: approximately 1 inch/min. of tape feed. The DC motor can be of the 2OOO rpm type used in car tape recorders. These have a very accurate built-in speed regulator. But it would be wise to use a mains motor for the Observatory model. The head required has one track for

seismic recording and one track for time channel, so an in-line stereo head will be the choice. For the observatory model a multi channel head would be the most economic and would depend on how many channels you would require for the seismometers feeding into this recorder. Stand off Playback facilities will be required for analysis, so the tapes can be studied without interrupting the continuous recording of the incoming data.
A bias frequency of around 60K/Hz, which is normal in most tape recorders, is good for this application. The seismic amplifier is simple when an I.C. is used. An AD 504 is an excellent choice for the circuit.

The timing circuit is again made up according to one's own requirements. One tenth of a second accuracy is suitable for general purposes and many pulse circuits and clocks are available, the pulse being recorded. Radio time pips can be recorded on the same track, or international broadcasts of time signals. Bias will be required for this purpose, as for the seismic recording head.

The battery supply can be a Gel-Cel type battery. This can be installed inside the recorder housing as it does not emit gases during discharge and no vent is required. But it is all right to use a lead acid type provided that you take care to vent this type and keep it clear of the other equipment. If the equipment is to be buried, make sure a plastic pipe to the surface is used; in these circumstances do not put the batteries in the same case. I have, where possible, kept the batteries isolated from the recorder.

The choice of seismometer is governed by the necessity to have the largest output for coil displacement. In the past, a Willmore Mark I and Mark II and Geotech S13 with around a 35OO coil has appeared excellent. The new Willmore Mark IIA seems to be an excellent choice on paper, but the author has not used one to date.

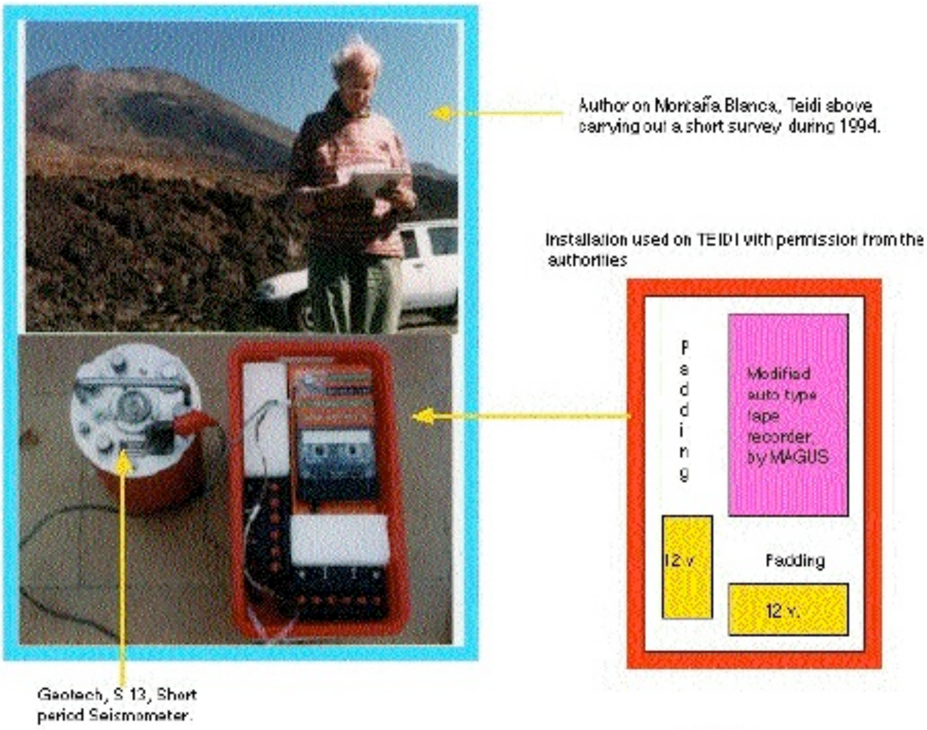


FIG 5

It is important to have a good sensitivity and high output because this alleviates having to have a higher gain and a basically noisier electronic circuit. It is better to choose the more sensitive seismometer. These seismometers are buried direct in the ground. Putting them on a base of concrete or other hard material is not advisable as this puts another resonant factor in the calculations. Just bury in the natural soil, sand, volcanic ash or whatever.

The whole recorder is best housed in a wood box (Fig 5) with a hard board lid and hinge of strong tape. It is advisable, when burying the instrument, to seal it with normal plastic insulating tape, which is replaced each time it is used.

A meter should be available to check the voltage, when switched on, to ensure the instrument is working properly; the only check that is needed. One switch puts both the tape and electronics in motion.

Apart from the mechanical modification of the seismic tape recorder, everything can be bought off the shelf. There is a company in England who can carry out the conversions. Details in Appendix 1.

Fig 5a: Replacing wind powered generator damaged by storm in the explosion crater area located between Ngauruhoe and Ruapehu New Zealand. One explosion crater can be seen behind to my left in picture. Active Ngauruhoe Volcano in background to my left.

Chapter III: FIELD ORGANISATION

The main aim of the field organisation is to turn in continuous records with full information, both seismic and time. The station, if intended for long-term use, can have a box built around it that will permit the operator to climb inside with the instrument in order to make checks and tape changes. A clear sheet of thick plastic is useful to make a temporary servicing tent over an instrument.

It is important to install the seismometer well clear of trees, poles, power lines, large buildings, footpaths and roads. A few metres of wire can easily be buried to set the seismometer in a more desirable location and yet keep the recorder and power equipment in a more sheltered, accessible place. Because of the lightning hazard, it is well to have everything buried as deep as possible and not to work on equipment during storms. The author has experienced lightning strikes which have damaged seismometer coils and, on one occasion, an amplifier, so it is important not to have wires laid on the ground. On the summit of a volcano a line from a seismometer lying on the ground was struck, damaging the seismometer coil and bursting the cable every three metres due to the "standing wave". This cable was quite a long one and also shielded so, where possible, the wire should be buried.

Adequate spares and, if possible, a complete system of spares should be kept handy, because it is essential to maintain continuous records. If the main base is located at the foot of, or on the volcano, it should be possible to run one of the stations there and ensure at least a continuous recording there.

For setting up a temporary or permanent seismic network on an active or dormant volcano, three or four seismic stations around the base can produce an excellent monitoring system; it is considerably enhanced if the fourth station can be set up near the summit, or at least half way between the summit and the base stations in elevation

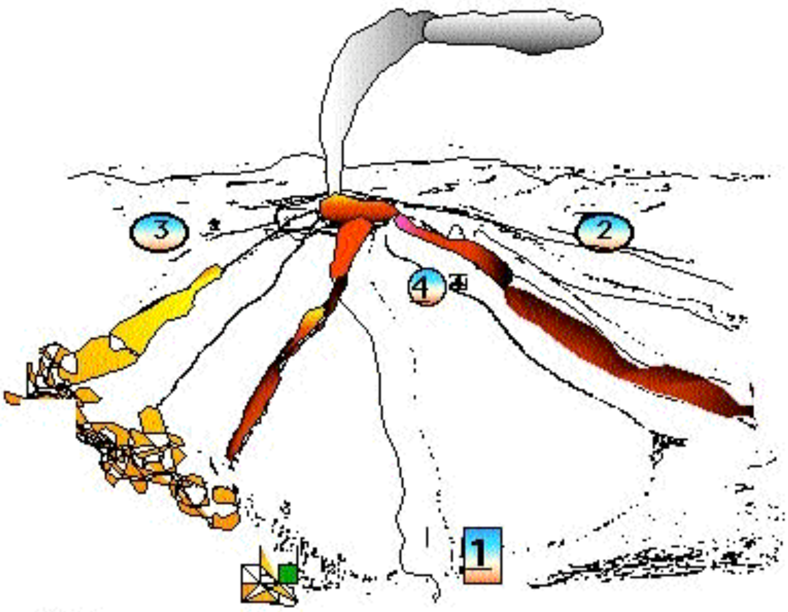


FIG 6

Typical station layout around volcano.

(fig 6). Station 1 and 4 are very important because, if magma gets to the level of station 1, it may become quite important if no summit or lateral activity is observed, to know whether the magma is still pushing upwards or retreating. An Observatory with uninterrupted recordings at station 1 with its own seismometer and possible satellite station or stations is depicted in (fig 6). But! if there is only one side of the volcano accessible, stations 2 and 3 will have to be ascertained by the person controlling the operation. Stations 2, 3 and 4 can be stand-alone portable ones, but a preference for a land-line connection to these stations feeding into one recorder at a small Observatory becomes, for long term recording, more sensible. It is important to set down immediately a tripartite network to turn in a much-needed background of information from a continuous record. The more continuous and long the time recorded, the better to establish criteria of impending eruptions, as were laid down by the author when studying Ruapehu in New Zealand.

If the Observatory scenario is not possible, and portable units will have to be employed, the attention paid to power requirements will be paid off handsomely in continuous records. Sufficient batteries and charging capabilities will be important. Large capacity l2VDC car batteries are always available. To charge these batteries in a remote area, a windmill type charger can be utilised (fig.5a), or a water wheel at a nearby stream or waterfall. Even a solar unit could be considered, but be careful to find out the behaviour of the sun, cloud and shade, trees, buildings, etc. on an annual basis. Solar panels work well in full sunlight.

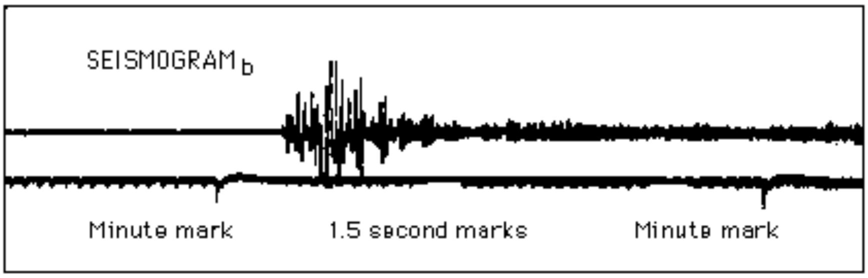
A visit to each station should be made as desired, as a full 7 inch reel of tape can last up to a month. It is quite a different matter to carry a tape reel in and out as compared to a battery. Motor generators should be avoided because of the noise and vibrations caused. It is also advisable to have two battery systems, each system automatically being charged alternately, with a daily switch over from charging to running equipment. This is important so as to avoid pulses and surges being incorporated on the seismic recording. This switch over can be achieved by a daylight sensitive switch or a clock contact every twenty four hours. It will be wise to remember that electrical storms are commonplace on volcanoes.

It is always better to make the field operators deal with less complicated equipment; often the elements of weather are sufficient to contend with without lengthy technical check-outs and tricky equipment that cannot stand being occasionally open to the elements. A big, and often forgotten, enemy of equipment is fine dust which is very abrasive and lies in ash emitted from volcanoes. There are also acids, especially H2S, which are emitted with steam and gases and will attack electronic components.

Cleanliness with equipment is a very important feature. It can never be overdone, as the environment around a volcano is similar to that of a slag heap. Even good earthing conditions do not exist, which makes radio operation very noisy. Lightning storms are usually vicious and very frequent, as are flash floods and instant fogs, and on the higher volcanoes snow and avalanches occur frequently. In the open it is a very good idea to bury the station. This eliminates a lot of problems such as insulation from heat and cold, radio interference, visibility to ramblers and larger animals, although some desert creatures love to chew plastic and wires, so bury them.

Chapter IV: DATA RETRIEVAL

There are several ways in which the recorded data can be analysed from a regular audio tape recorder (fig. 7) without any further complexity of equipment. Practically all this analytical equipment is available off the shelf. A good basic set up would be as in (fig 8) which is used in everyday electronics.



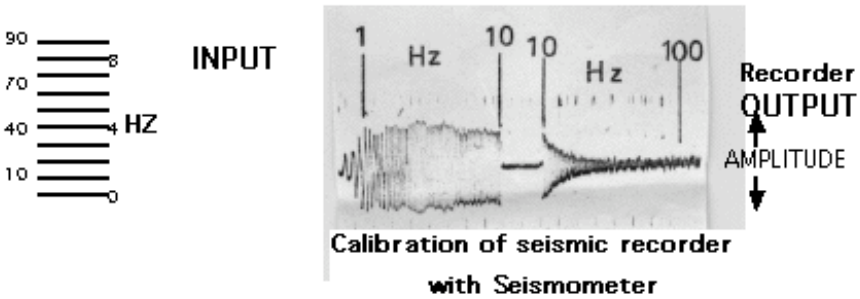


FIG7.

All audio frequency and vibratory analytical equipment can be used because of the speed-up of the recorded data for playback at 9.5, 19 or 38 cms/sec., which puts the seismic frequencies into audio frequencies.

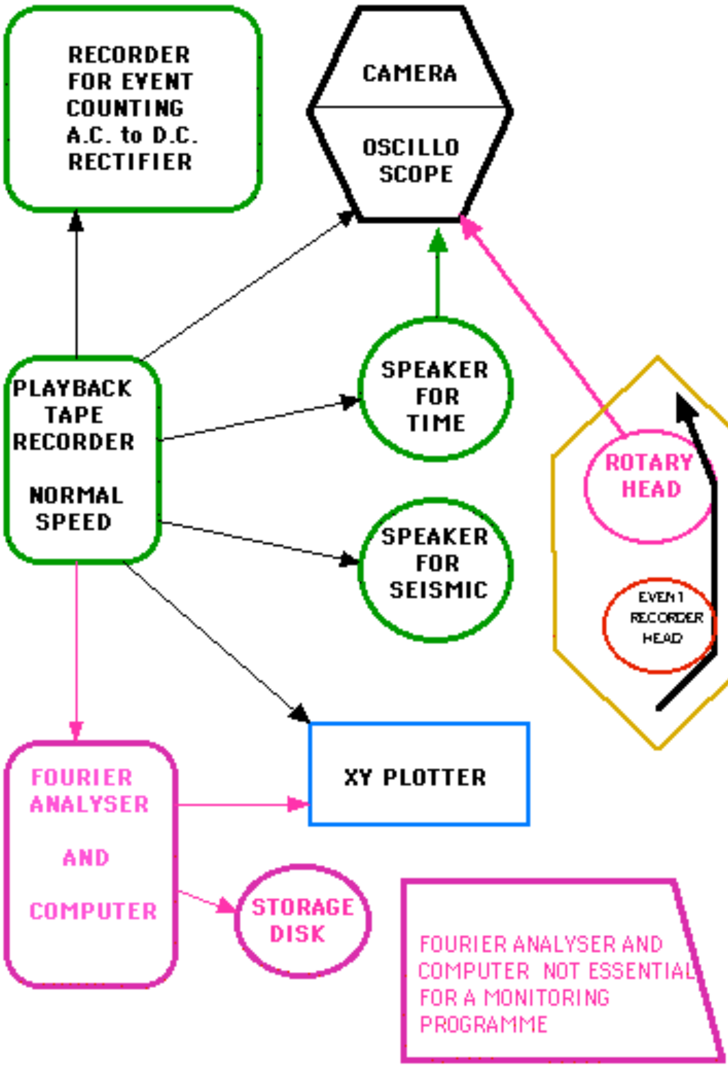


FIGURE 8

These audio frequencies can be listened to by ear and viewed on an oscilloscope screen or notations made on a DC chart recorder.

This can give a very quick picture of the build up of events, and is the best tool when predicting is necessary. Instant records are paramount for predicting with any accuracy the oncoming eruption. With a permanent observatory set up and the rotary head (Fig 4) providing instant readout, this technique is invaluable.

The recording can be played into a chart recorder or memory oscilloscope for permanent record, or fed through audio filters to reproduce various event information that the operator requires, with certain frequency elements of interest. In fact, the tape record lends itself to even the most sophisticated analysing equipment, such as the a Fourier Analyser and computer with direct digital conversion for Analogue signals.
A slow motion tape recorder can be situated in an observatory (Fig 4), with the ongoing seismicity being recorded - especially if land lines are directly feeding into this observatory. A recorder can be modified to take a rotating magnetic head, which will scan the piece of tape that is in contact with the head. A certain amount of the tape can be allowed to wrap partly around the rotating head, so as to scan at least one half minute of real time of the seismic signal arriving at the recorder. This can be coupled to trigger the trace on an oscilloscope, so the rotating head gives a constant moving picture, just as a movie film appears to do. Wiper contacts from the head can be used to transmit the signal from the moving head to the oscilloscope. A wiper-contact can also be used to trigger the oscilloscope trace. This is the best way to handle the data leading up to an eruption, especially if you use multiple channels displaying all the

seismometers, in the same time scale. In other words you can view the seismic events directly that are actually happening, with only a slight delay. This gives a hands-on approach to the progress of the eruption at all stages. Even if stations get cut off, the eruptive progress can still be monitored, giving on-the-spot predictions.

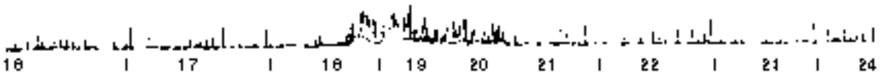
Cameras of most types can be utilised to photograph these stationary records. The author uses the combination of a Hewlett Packard battery driven 1703A oscilloscope, which has the memory feature, and captures the events with a Polaroid SA7O or a digital camera for permanent record and quick report use. This set-up can be used in the field, with a small battery driven replay recorder which is very light and portable.

CHAPTER V: TABULATION AND ANALYSIS LEADING UP TO AN ERUPTION

Assuming that the equipment depicted in (Fig 8) is available, we can start looking for the events that the author had identified. It would be wise, at this stage, to refer to my original paper (Appendix 2) to see how important it is to study all events and to make up a picture of what events relate to the activity that precedes an impending eruption, and the strict implementation of preparing the charts showing the relevant information, as discussed in the following paragraphs.
Isolated apparent explosions or sudden low-frequency outbursts, not having onsets as for normal earthquakes, occur frequently in the vicinity of active volcanism. These should be counted and categorised in as many ways as possible, with local, medium distance and distant earthquakes all separately listed. Earthquake swarms sometimes occur with up to one event every 3O seconds. Another interesting sequence of events is the occurrence of local earthquakes which seem to appear as a stepping function, up from or away from the first event in sequence. There are also events which have obvious echoes. (Listening technique).
The listening technique is very important to aid in deciding what type of events these are. It would not be wise to employ someone who is tone deaf. The essential element of this technique is how quickly a lot of data can be sorted, by the simple technique of listening to the speeded up tape and making notations at the same time, on a chart recorder reading the same record as a D.C. playout (Fig 9) - at the same time listening to the data with notations on the record of events on the DC chart. This also provides an energy figure for all events and an overall background. The author found that eruptive periods fell into an overall diurnal pattern, which rose and fell in very long period patterns. These patterns were over several months and, by comparing a few years of DC playout charts, the outbursts of varying size seemed to coincide on the third long period rise, which was notably higher than the previous two. These I classified as a kind of volcanic diurnal periodic pattern, not coinciding with moon, magnetic, gravitational diurnal phases, which made me conclude that all these diurnal patterns are self-motivated in the Volcanic case, possibly caused by the rise and fall of magmatic pressures, within or acting on the earths mantle. It appeared to have a diurnal periodicy of approximately three month's on Ruapehu.

D.C. PLAYOUT, SHOWING NOTATIONS MADE ON THE PEAKS OF EVENTS. THE OVERALL RISE AND FALL OF THE BASE SIGNAL IS THE LEVEL OF TREMOR. IT IS IMPORTANT TO SEPARATE WIND MOVEMENTS FROM VOLCANIC TREMOR, THEY CAN RAISE THE BASE SIGNAL AS DOES VOLCANIC TREMOR. BUT AS VOLCANIC TREMOR IS A VERY PURE FREQUENCY AND WIND IS A MIXTURE OF MANY VERY UNSTABLE FREQUENCIES. THE LISTENING TECHNIQUE SORTS THESE TWO OUT EASILY. THIS CHART HAS LITTLE EFFECT FROM WINDS WHICH HAVE TO BE AT LEAST GALE FORCE. THE INTERFERENCE TO THE TIME CHANNEL DURING THE ERUPTION, WAS CAUSED BY CROSS TALK. THE CAUSE WAS HIGH OUTPUT FROM THE FIELD SEISMOMETER, BETWEEN A LINK

OVERLOAD OF TWO POORLY SHIELDED PAIRS, LINE AND TIME, AND HIGH OUTPUT TREMOR.



TIME CHANNEL WITH GMT + 2YA TIME PIPS.
THIS IS COPIED FROM A PAPER BY G.R.T.CLACY. PAGE 2 PRINTED AT THE END OF THIS DOCUMENT. THESE OBSERVATIONS WERE MADE AT THE CHATEAU OBSERVATORY TONGARIRO NEW ZEALAND. JULY 1966.

FIG 9

Another form of event that has its own characteristic is chuffing tremor. This tremor appears as volcanic tremor, that is, modulated, and occurs after an eruptive period. It appears as if the magma retreating down the conduit keeps being impeded, rather like the motion of waves on a shore as the tide is going out. I believe that, if chuffing tremor does not occur, the magma will cool down and fill the conduit, so the next outburst from the volcano will take a different outlet course, or it will be contained with no further eruption impending.

Subtle changes of frequency and energy levels should be carefully noted as these have been shown to mean a change of mode of the volcano under study. New activity to a change of eruptive site, even lateral breakouts from the volcano, can be expected. Now all eyes should be focussed on the volcano under study, viewing physical changes and making careful note of all observations made. Observed data, dates, times, etc., should always be noted; sometimes correlations of seismic data and observed data, can not become obvious until some time later. Histograms (Appendix 2) can be made concerning all data which help in following the stage at which we expect to be looking towards an impending eruption or quiet period.

Individual deviations of events should be studied closely for clues (fig 10) of overall changes taking place. Seismograms should be made of events and also frequency analyses of events and tremors. It is sometimes a long wait for an eruption. But many interesting events can be studied with possible use later.
It is always good policy to be ahead with plots and equipment maintenance, as personnel will be more than busy when an eruption takes place. Constant familiarisation with both analysis and equipment is of the utmost importance for a successful monitoring programme.

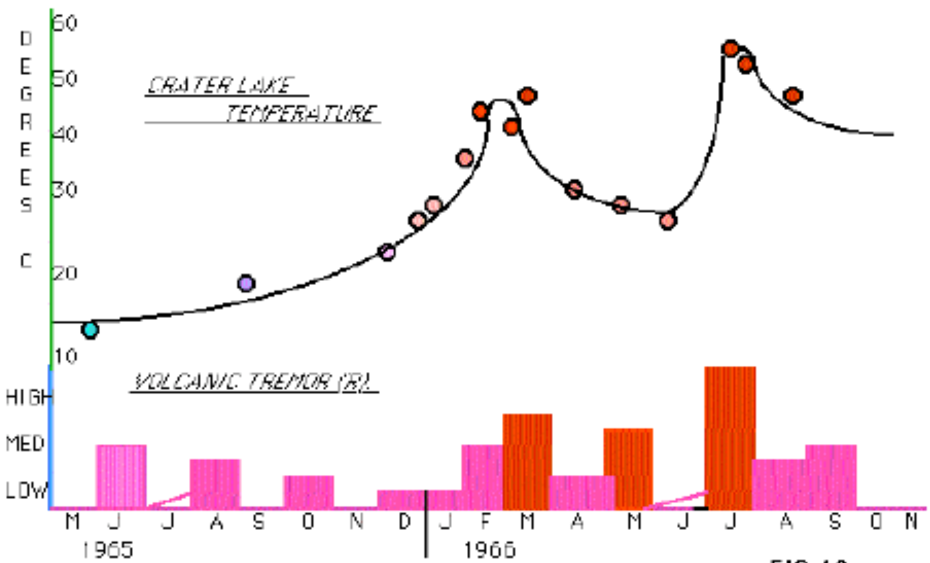


FIG 10

Lake microseisms (APPENDIX 3) should be identified when operating within a few kilometres of a lake; these are within the frequencies of interest and must not be included as for volcanic tremor.

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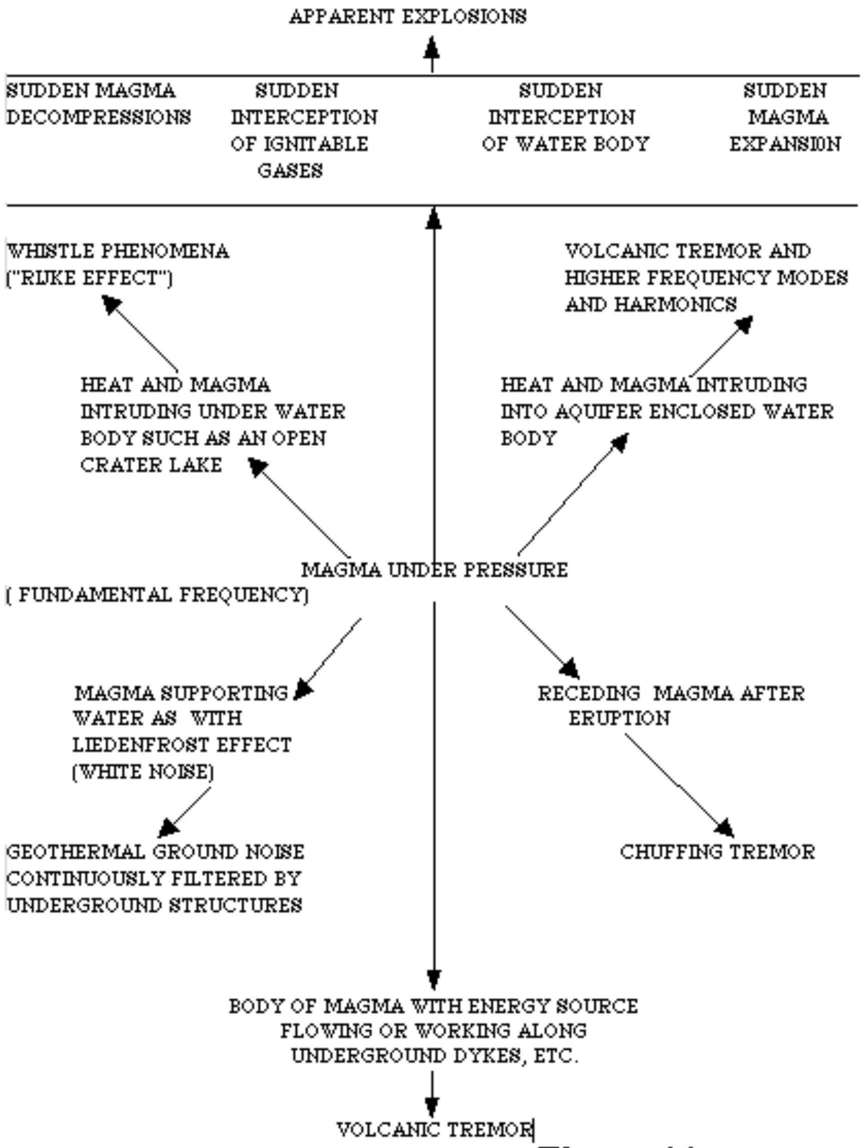

Figure 11

A list of events (fig. 11) and a glossary of terms, below, suggests causes of the different phenomena showing magmatic motion as the fundamental origin of all volcanic phenomenon.

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GLOSSARY OF TERMS

BAROGRAM
Chart indication changes in atmospheric pressure.

FUNDAMENTAL
Basic initial frequency from which harmonics stem.

HARMONIC
Frequency derived from fundamental frequency. Can be any number of multiplications.

HARMONIOUS
Nice, even sound or frequency.

MAGMA
The molten fluid formed within the crust or upper mantle of the earth.

MAGMATIC ACCEPTANCE
Materials accepted, either by chemical reaction, temperature reaction or pressure reaction.

MAGMATIC DIFFERENTIATION
Rejection & acceptance in various differential modes & mixtures.

MAGMATIC REJECTION
Materials rejected, either by chemical reaction, temperature reaction or pressure reaction.

MAGMATIC WATER
Water arising from an underground magmatic source; sometimes referred to as juvenile water.

MURPHY'S LAW
If anything can go wrong, it will.

SEICHES

A variation in the level of the surface of a lake, resembling a tide, caused by volcanic activity, earthquakes, etc

Chapter VI:

APPLICATION OF RESULTS & SUMMING UP

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If the success of continuous records is good, and some months or years of data are compiled and compared, it may be possible to operate one seismic unit to cover the general background. Then, when things appear to be livening up, such as volcanic tremor the satellite recorders may be deployed quickly to already-prepared sites. Hopefully with previously recorded background outlining the type of record to be expected. A.M. recordings are good, because the dynamic range of the signal is very wide and one should consider the amount of gain that can be applied in the laboratory to the recorded data. Ninety decibels of dynamic recording range is not a bad tool with which to work, when other types of systems rarely exceed thirty decibels. We have a range, from large signal types of earthquakes to the most minute type of ground motion to be considered, and all add their particular part to the necessary background of an eruption, so the dynamic range is very important.

Scales of when the alarm should be made can only come with experience of events that can be correlated with eruptions. Whether a certain number of volcanic explosions or apparent explosions, coupled with volcanic tremor of particular levels, give warnings, only experience can dictate. Over-prediction can lead to disbelief, whereas under-prediction leads to mistrust, especially from people living at close quarters with the volcano. Probably it is hard to stop oneself from over or under reactions, because some predictions may not happen, or others occur that were not foreseen. This will be kept to a minimum if the observer takes, or is allowed, the time required to set up and observe eventful and non-eventful periods of the volcano under study.

From my experience, when the volcanic type of events occur seismically, other signs of activity start to show. This, in most cases, shows in the form of emissions from the crater, like the correlations made in (Fig 10), Crater Lake and Volcanic Tremor. In this case we were fortunate to have a hut which contained a thermometer, close to the lake, and random visits were made to take the measurements of the lake temperature and record them. When the lake reached its maximum in July 1966 the lake had become very acid - a mixture of Hydrochloric and Sulphuric acid - strong enough to clean some coins I had in my pocket. Since that time the hut was destroyed in a recent eruption of Ruapehu.

It has been found that, on most volcanoes which have seismic monitoring equipment on the lower flanks of the volcano under study, most events are recorded that occur within the confines of the volcano. Even when a large fault runs right through the volcano this holds good, though minute delays and a small frequency shift may occur. If it is felt that this is significant, then it would be advisable to have a station on both sides of this fault or rift for continuous monitoring. This can be determined quickly with portable equipment.

It is a good idea to keep a record of events plotted and displayed in the observatory, or wherever the analysis is made, and kept up to date. The presence of this information at a viewable level adds to the dramatisation of the job in hand. After all, this kind of operation, both for support and end product, is totally dependent, as a rule, on the public. Its aims are to allow the early warning to be made, so as to save life and movable property by alerting the public at times of build-up of activity on the volcano or volcanoes of the region.

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Epilogue

Prediction of an oncoming event precisely is probably the most difficult task in the world. A volcano is probably less difficult to predict because it has a single motivator, which is magma. Magma has to move its mass in quite a big way, mainly because it produces material out of the vent, in large quantities. Magma produces as it proceeds up through the outer layer of the earth's crust. So when the prime motivator begins to move up through the earth's crust, the detection of its progress is the first most important piece of information to learn about . Then continuing to follow its progress. Unlike an Earthquake, which is a much more earth shaking event, a volcano usually occupies a very discrete area and has the capability to move literally mountains of material out into a fairly small area. It can continue its output for very long periods, sometimes at quite a fast rate dependent on the make up of the material. We can suppose that, if the venting of the material is dragging pieces of the underlying cold material, that is the eruptive material, it can collapse back into the void it has just vented from.

This was the case for the Cañadas Volcano on Tenerife, which, according to studies, was almost twice the height of the present day volcano and collapsed back to the level of Las Cañadas. Teide being but an afterthought sticking out on the Northern flank of the present day volcano. The Cañadas is a region I studied for three years with permission when I retired. I owned my own "seismonitor" and made a few recordings which were very interesting. I did not write a report as I would have required more time recording and my equipment was vandalised in the Cañadas region. Counting the cost I quit. There was another element of danger apart from the volcano at large. But I still like toying with the subject; volcanoes seem to be a live entity, with a will we would like to control, even better predict its moods which I believe is possible with the right equipment and mind. Using the listening technique, which produces an on the spot intriguing quick result which seem to be uncomputable, and goodness we have tried. The evaluation of events seems to take on a new meaning, and produced an exciting tabulation of

events as they happened.
My equipment was taken on an oceanographic seismic crustal survey, in the Southern Pacific on Bikini Atoll. After the survey the tapes were returned to me for analysis using the listening technique. The analysis coincided with the normal crustal recording also made at the same time with one exception, one could hear one or two more arrivals not discernable on the regular much more supposedly sophisticated equipment. These arrivals I termed ghosting, but in reality we had a better dynamic range using our seismonitor.
After retirement I studied Tenerife from my apartment in San Vicente with written permission from the authorities. I became puzzled with the activity a few Kilometers North of Puerto de la Cruz, which brought to mind of an underwater seamount. These seamounts are sometimes the beginnings of a new volcano.

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At the time of writing, **Author and Geophysicist G.R.T.CLACY lives in the UK** and can be contacted by email:

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Appendix 1 Terms used on Estimation Charts, Diagrams And in the Text etc.

Appendix 2 Analysis of Seismic Events Recorded with a Slow Motion Tape Recorder near Chateau Tongariro New Zealand during February 18, 1966 to December 31, 1966.

Appendix 3 Local lake microseisms recorded near lake taupo in the north island of New Zealand.

Appendix 4 Geothermal Ground Noise Amplitude and Frequency Spectra in the New Zealand Volcanic Region.

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