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The Development and Impact of Harmonic Reformed "Miche" Wavelets Upon a Natural Beach

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ABSTRACT

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The development of multiple or harmonic reformed waves following sea waves passing over or breaking on reef structures and in laboratory wave flumes containing artificial reefs or plates has long been noticed. However, this phenomenon appears to have been accepted as a comparatively minor oddity of only secondary concern. Yet on some natural sediment-rich beaches, these same wave harmonics occur, and they nearly completely dominate the behaviour of the shoreface and the visible beach. The Gold Coast of Queensland Australia is one of these beaches, and we report herein of an initial study into the development, impact and incidence of broken wave harmonics on this beach system.

ADDITIONAL INDEX WORDS: *Waves, beach, harmonics, reefs, coastal engineering.*

INTRODUCTION

The manufacture of multiple crested or reformed harmonic waves by swell trains setting up or breaking over submerged reef structures has long been noted, see for example WIEGEL (1990) and GALVIN (1990); but little study appears to have been carried out upon how these harmonics form, why they form, and what their impact is upon the beach.

The phenomenon when associated with offshore reef structures is not common, although when it occurs it is very obvious. Wave harmonics also can occur on purely sandy beaches when there exists an offshore sand bar or a series of them. The Queensland Gold Coast beach system is one of these where reformed harmonic waves are ubiquitous and represent much more the norm than the exception. Long term studies have in fact shown that these multi-crested waves completely dominate the behaviour of the swash zone and visible beach. When they were first investigated on the Gold Coast in the mid eighties, they were given the local name "Miche" wavelets after ROBERT MICHE (1944) who demonstrated that a multiple or harmonic wave train was theoretically possible and quite stable and this name has stuck.

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HISTORY

A strange feature of coastal engineering is that while we often have a sound intuitive knowledge of the behaviour, we often don't look at the actual processes which can be very complex. We can start to believe we know everything about beaches—they are made from sediments, particularly above water, the waves break close to the shore, the broken bore runs up the beach, stalls and then runs back as the backwash; all very elementary indeed. Yet the behaviour of high energy ocean beaches is remarkably subtle and variable and many processes may co-exist simultaneously but the blend of processes may change continuously. Natural beaches perhaps deserve a great deal more attention and observation than they get. In this, the Gold Coast coastal engineers have been no exception. In the mid seventies the engineers noted that when the first break in a swell was breaking on a bar, the water between the initial break and the final secondary break on the swash zone often looked confused and "bumpy". The engineers of course "knowing all about beaches already" overlooked the phenomenon as a minor unimportant side-product detail, and it never occurred to them to seek a cause or a mechanism. How wrong we were!

It was another ten years before we managed to

take another tentative step. In 1986, a trial preliminary field study of surfbeat was mounted and for the very first time one of the engineers thought to time, with a stop watch, not only the initial wave break but also the final wave break onto the swash zone as well. The results were astounding to us. For weeks on end, the swash zone wave always held a period of half the initial break and for a lesser proportion of time, a period of a quarter. Something very strange was happening out there and it applied to all our nearby ocean beaches and for nearly all the time. We *were* addressing pure wave harmonics, the half and the quarter but strangely enough never so far, the eighth—but we still did not know why. Similarly WIEGEL (1990) did not report reef multiple waves of more than the quarter harmonics, he actually quoted a 14 second swell with "about" three second resulting wavelets.

When the surfbeat preliminary study was completed, the engineers turned their attention to the "Miche" wavelet problem and commenced as a trial daily observations of the local beach at a constant location, a project which later became the daily Gold Coast Beach Log Data Collection Program. Again as an aside and an example of how slow a local beach observer's learning curve can be, it took nearly another two years before the engineers learned what data *was* important and *should* be collected! This was not an insignificant waste of effort in full hindsight.

As the daily data began to flow in, it was analysed sequentially, initially in three month increments, then six months, and finally annually. The lessons as they emerged were:

(a) The development of "Miche" wavelets was always associated with the occurrence of an offshore bar and trough topography. If there was not an offshore bar and trough, then the incident deep water waves broke close inshore and resulted in only continuous broken wave bores, that rushed up the swash zone without alteration.
(b) The offshore bar was at times very "active" but for most of the time it was a relatively stable relict structure.
(c) The period of the "Miche" wavelets was not constant, *e.g.*, a ten second swell could produce "Miche" wavelets with ongoing periods of four seconds and six seconds, but the *celerity* of the "Miche" wavelets *was* constant. That means that the wavelets generally maintain their separation until after they have been converted to bores on the swash zone after their final break. This irregularity of the final shore break and bore deceleration period also produces a surfbeat. If all the bores were of constant period and celerity, there would not be any surfbeat in this zone. From our observations, the celerity of a final broken wave bore seems to be controlled by its height, which seems very reasonable; yet we currently cannot explain this phenomenon in any practical terms. We only see how the bores actually behave and wonder.
(d) Quarter period wavelets are produced only from half period wavelets on a double bar, double trough beach, *i.e.*, a progressive double "split".
(e) On the Gold Coast, from the yearly analysis of the daily records, "Miche" wavelets are present for something of the order of +90% of the time.
(f) The maximum height of the bores and the resulting reformed "Miche" wavelets is approximately one half the height of the breaking waves.

It thus became rapidly obvious that "Miche" wavelets are a dominant and important feature in the surf zone of our local beaches.

GENERATION PROCESSES

Given that we accept that real shoaling waves on a real sandy beach consist of two parts, it is not difficult to deduce a mechanism for the manufacture of "Miche" wavelets. Shoaling waves consist of a surface form above sea level energy and a submerged orbit field. As a first approximation, we assume potential and kinetic that are equal up to breaking the energy contents of the shoaling wave form. Field observations then suggest that on breaking, the surface form collapses to make the immediate local wave set-up and the orbit field becomes the broken bore that continues forward towards or straight onto the swash zone. Nature however will always try to reform and rebalance a broken wave and balance the potential and kinetic energies by converting part of the broken orbit field back into a surface form.

When a wave initially breaks and forms a bore, the disturbed orbit field smears out along the surface of the water, but if the water after breaking is deep enough, then half the bore orbit field will swing from horizontal to vertical, and the new

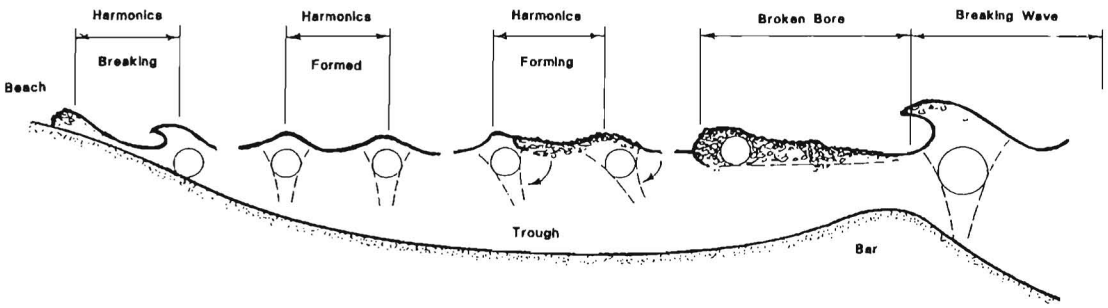

Figure 1. Deduced method of manufacture of harmonic Miche wavelets. Note truncated orbit field due to shallow water. Broken bore wavelength same as breaking wave. Harmonics form at half this. Each Miche wavelet maintains same celerity as breaking wave and broken bore less deceleration due to progressive seabed drag. Orbit field of broken bore is horizontal on water surface.

surface form will rear-up and ride on top of the orbits. If the water after breaking is too shallow, such as on a constant shoaling profile (*i.e.*, no bar and trough), the bore cannot reform so it continues shorewards in unchanged form with its orbit field still strung behind nearly horizontal and usually in complete contact with the seabed. Reformed waves can thus only occur where there is a seabed bar and trough or reef and trough topography, and in fact you can accurately enough deduce the seabed shape by simply *looking* at the incoming wavetrain shorewards of the initial break and noting what it is doing.

However, the factors that control whether a broken bore will remain a bore, reform into a single wave or form a half period wavelet are not yet well understood; the indications are that the control relies upon a combination of wave length after the initial break and the water depth in the trough. If the trough is very deep relative to the wave length, a single reformation may occur, but if the trough is shallow as it usually is on sandy beaches, the broken bore splits into two, each half of the orbit field rotates down and two wavelets are formed. Commonly the half harmonic waves maintain the same celerity, *i.e.*, they cannot catch each other up but the leading wave of the new pair, forming from the taller *front* of the bore, is usually the larger in height. The deduced sequence for the manufacture of "Miche" wavelets is shown in Figure 1 which is self explanatory.

IMPACT OF "MICHE" WAVELETS ON THE BEACH

The impact of "Miche" wavelets upon the swash zone and visible beach is profound. The swash zone, in particular, only feels and responds to the actual waves that reach it and not what is happening further offshore, particularly the deep water wave train. The advent of a bar and trough plus "Miche" wavelets therefore cuts the beach into two completely different zones, the outer responding to the deep water wave until it breaks on the bar and the inner to the "Miche" harmonics when they exist. If two bars and troughs develop, then the beach is cut into three zones, locally quite a common development during great storms, but either way, the bar-trough-Miche system and sequence is Nature's most potent way of conserving the beach.

We can gauge the impact of a two storm bar and two trough beach system without the development of "Miche" harmonics and with them in terms of applied wave energies. As a reasonable approximation, we take the wave energy to be proportional to H^2 and L as linear. Since field data show that each wave reformation and larger "Miche" wavelet holds half the height of its original breaker and the wave length is halved by a half harmonic "Miche", then the crude resultants based on the wave energy just prior to breaking will be as set out in Table 1.

In coastal processes, nature to us appears to be

Table 1. *Wave energy impacting on beach.*

Beach State	1st Bar	2nd Bar	Beach
(a) 2 Bars, 2 Troughs No Miche	100%	25%	6.25%
(b) 2 Bars, 2 Troughs Two Half Period Miche	100%	12.5%	3.13%

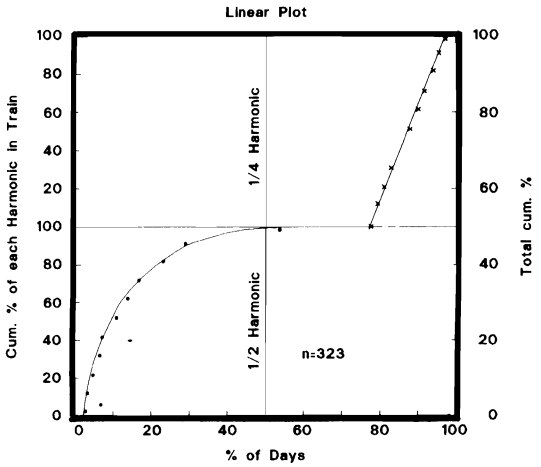

Figure 2. Miche wavelet frequency.

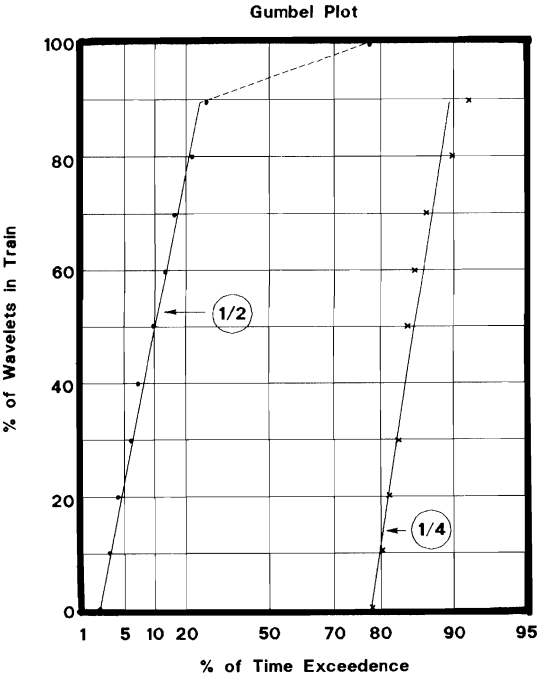

Figure 3. Miche wavelet frequency.

extremely smart when it comes to optimising and conserving her resources.

The development of inshore "Miche" wavelets can result in some very strange sights. On the Gold Coast during a heavy sea, we have watched the offshore wave break migrating offshore and eroding the seabed while building its far storm bar; yet, at the same time on the swash zone of the *visible* beach, the second set of very short period "Miche" wavelets was very actively *accreting* the beach as we watched! The occurrence of "Miche" wavelets also exerts a great deal of uncertainty into the study and modeling of natural beaches. Many beach response models rely upon analysing beach shapes that simply mean out any bar-trough structures, and then for purposes of analysis consider only the deep water properties of the waves and not those that actually reach the beach. What benefit might there be in attempting say, to calibrate any model using deep water wave period or length when a double "Miche" system exists at the time and a determination is made that the actual shore-landing wave length is a quarter of that? That would be a rather significant error of fact or error of assumption, in *any* model, and any like assumed error in wave height could make everything worse by nearly a magnitude or two.

One thing we on the Gold Coast do not know is how widespread the phenomenon of "Miche" wavelets is around the world. From direct observation in South Eastern Australia, the phenomenon has been seen on various beaches near Sydney, about five hundred miles South of the Gold Coast, in various terms of intensity. Our data on the U.S.A. is unfortunately much more sparse. Neither of us, from on the ground or in the air, have noticed the occurrence of "Miche" wavelets between New Jersey and Charleston, nor on either coast of Florida, but we have never visited these places and found waves higher than 0.75 m; usually they are much less. You need larger waves than this to easily detect Miche harmonics. However, on the Western seaboard one of us has observed half period waves near San Francisco, and at the American Shore and Beach Conference at Huntington Beach (November 1992), it was noted that from a 0.9 m × 7.25 second swell, pure half period "Miche" wavelets were produced continuously for an hour and a half at each high tide.

FREQUENCY

Although along the Gold Coast "Miche" wavelets are present in reformed shoaling wave trains for most of the time, it is still for only part of the time that the reformed train consists entirely of these harmonic forms. For much of the time, the

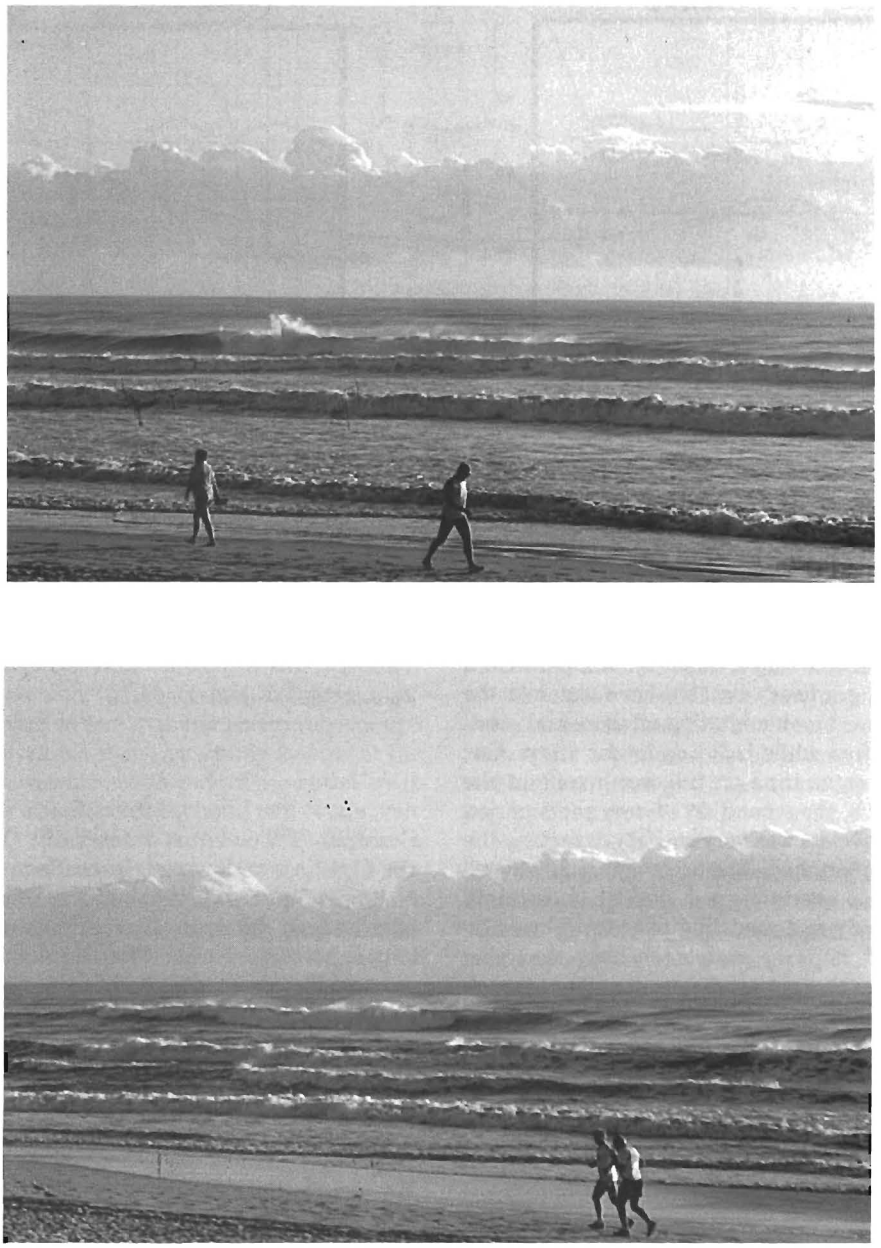

Figure 4. A. Pure wave train breaking. Station 2 Alpha 17th March 1991. (Deepwater period = 7.1 sec H sig = 1.8 m.) B. Same beach, same wave train 5 minutes later with full half harmonics running. C. Example of half and quarter harmonics (Station 2 Alpha 16th Sept. 1991 Dead low tide). Deepwater period = 10 sec, H sig = 0.6 m. Breaking initially close coupled, but identical celerity. Inshore harmonics, however, are nearly equally spaced. Percentages of waves reaching shore: offshore train t = 10 sec 25%, half harmonic t = 5 sec 50%, and quarter harmonic t = 2.5 sec 25%.

Figure 4. Continued.

inshore broken wave train will contain a mixture of "Miche waves" that have reformed from the larger deep water waves plus smaller deep water waves that are not large enough to break on the bar and reform. These latter waves come straight through and become interspaced with the "Miche" wavelets, inshore of the bar; they *all* hold the same celerity.

Data upon the local frequencies of "Miche" wavelets is obtained by manually counting and timing the waves reaching the swash zone for between five and ten minutes each day; the time is dependent upon the degree of the complex and variable nature of the shoaling train. From this a partially subjective count for mixed trains or an accurate one for constant trains can be made for each class or mix of waves. As a long term database (four to five years of daily readings) is an invaluable asset but expensive and time consuming; it is our policy where necessary to accept partially crude measurements, as long as we take a very large number of them. We thus generally aim for the simplest measurement techniques and analyse the data in long term suites to assess the variability and effective application accuracy, purely in statistical terms.

This work is ongoing, but the data for a nominal year in 1992 (actually 323 days) is shown as a cumulative percentage plot of percentage of "Miche" wavelets in the train each day in Figure 2. The total cumulative percentage is shown on the right of the graph and, on the left, the separate percentages for half and quarter harmonic wavelets. As can be seen from the figure, on only 2% of the days were there no "Miche" wavelets at all but the dominant presence was for half harmonic wavelets to be present for nearly 50% of the time. The Miche formation processes that develop before any quarter harmonics can form at all are obviously associated with a major physical threshold, *i.e.*, the growth of the second bar and trough is necessary but why this is so is not at all yet well understood.

As a provisional statistical analysis the data for both the half and quarter harmonic "Miche" wavelets is shown as Figure 3 on Gumbel probability paper. This is not actually a proper statistical presentation; it has been folded so that both

harmonics are shown to 90% of the number of wavelets in the train both to the same vertical scale, but the horizontal percentage number of days is continuous. A time plot would have been twice as high with a horizontal zig-zag at the 100% half "Miche" threshold showing; but our interest in this crude presentation is that it strongly suggests that the threshold barrier aside, the percentage of half and quarter "Miche" wavelets as separate populations in the wave train each day must be surprisingly close to a very good Gumbel fit. This might be quite astonishing considering the imprecision of the daily readings as discussed above but it does seem to indicate a real trend.

Again, why this might be so is not properly understood. However, as pointed out for example in SMITH and PIGGOTT (1993), the only two other beach parameters on the Gold Coast that *are* Gumbel are the swash zone slope and the surf beat period. If we associate like with like, we might begin to appreciate that "Miche" wavelets may have a great deal to do with manufacturing the local surf beat or even perhaps they may dominate it. This possibility at the present, however, is still only the basis for another future beach long term process investigation.

HARD BAR GENERATED "MICHE" WAVELETS

In all the above, we have only considered "Miche" wavelets as generated on the prototype leewards of "soft" or porous sandy bars. In Nature, reformed waves are also formed by incident waves traveling over impervious or "hard" structures in the form of rocky reefs, *e.g.*, WIEGEL (1990). Few detailed studies of prototype reef induced wavelets have been made, but as WIEGEL (1990) and YOUNG (1989) have observed, reef "Miche" wavelets often do not reform as precise harmonics, but the periods can be irregular and probably usually they are. No explanation for this has yet been offered but it seems that on a soft sandy bar and trough seabed, the waves themselves probably mould the seabed such that precise harmonic periods are attained, a dynamic feedback system that would be impossible on a hard rocky immovable reef. Some hard bottom reef wavelets research has also been carried out in small model wave flumes; from the literature we read, much of the work appears, like ours, to be of an ad-hoc nature, generally carried out in isolation. Furthermore, a fair proportion, or possibly most of this work, *e.g.*, REY *et al.* (1992) has to date been limited to rectangular reef shapes which reflect wavelets off the leading vertical face as well as wavelets escaping off the trailing face. The applicability of these models to "Miche" wavelets on the prototype appears to be low. The major exception may be the work of BEJI and BATTJES (1993) where a more naturally shaped (but hard surface) bar was studied, and the flume generated clear harmonic wavelets. However, much of the data presented is difficult to interpret because the maturity of the flume wave (*i.e.*, its degree of being a soliton) is unknown, and the degree of flume resonance and reflections off the hard reef and beach are also unknown.

CONCLUSIONS

A preliminary study of reformed harmonic "Miche" wavelets on a sediment-rich high energy ocean beach is herein supported. These wavelets can exert a profound impact upon the visible beach and they are a powerful factor in the absorption of wave energy in the very near-shore beach zone. At present the precise mechanism that produces these wavelets is unknown but a conceptual model, based upon thousands of hours of on-site observations, is introduced. We conclude that the wavelet phenomenon observed on the Gold Coast beaches may well merit a great deal more study and research.

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POSTSCRIPT

The initial discovery of multiple wave harmonics, or Miche wavelets, as we call them, was very certainly never made by SMITH in 1983 and (as

usual for Gold Coast data) not reported, until 1993, at *Waves 93* conference at New Orleans. Nor was the same discovery made by CY GALVIN (1990) as referenced above, nor by BOB WIEGEL, with his original reference in his definitive text "Oceanographical Engineering" (1964), but the original discovery must be that made by WARREN THOMPSON, later Professor of Oceanography at the Naval Postgraduate School, during his service as Lt./j.g. in the U.S. Navy, during the invasion of Palau in 1944.

THOMPSON's quote to the writer (*personal communication*) is—"My first experiences with Miche wavelets, was during WWII at Palau, where I had the job of forecasting and observing the surf and beach conditions for the landing there. I had just come from Scripps Institution of Oceanography where I had been taught the then newly developed technique of forecasting sea and swell in deep water and also shoaling and refraction to the breaker point. The shoaling method was developed for waves arriving on a sloping beach without bars. LO and behold, when I flew over the proposed landing beach a few days in advance of D-Day, swells were passing over a barrier reef into the lagoon and the waves ending up on the beach were low and of much shorter period than the swell. Being suddenly caught up short in a critical situation, I threw out what I had learned about shoaling and improvised my own method of describing the beach and surf hazards there. Since then I have become familiar with bar-modified waves from several years spent on the Gulf of Mexico coast." The writer thinks that no further comment is required, as far as the writer is aware, SVERDRUP and MONK, or C.A.M. KING for that matter, never worked upon barred beach dynamics, or the wave forms that resulted therefrom. THOMPSON, we think, remains the first observer of the whole phenomenon.