Frequency Seriation and Temporal Order.
A Zooarchaeological Study

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Abstract. This paper presents the results of a frequency seriation analysis of bird bones remains from a South American shell midden. The purpose of the analysis has been to evaluate the differences in bird consumption during between 9 archaeologically identified occupations. We intend to study the possibilities of correlation between time and site formation processes. We assume that changes in the nature of bone assemblages are related with changes in consumption (there is an increase of refuse material from most commonly consumed animals), which are also related with changes in productive systems (technology) and social demand. The statistical relevance of butchery marks in different archaeological layers is analyzed to evaluate the social dimension of animal consumption. The paper studies whether people inhabiting the site needed intensify the consumption of less profitable resources (birds), when the availability of the most important one (sea mammals) declined. The study of butchery marks across time should offer us the possibility of examining the increase or decrease in the number of marks per item, the average of marked fragments at each time step, and the variability of butchery marks between different species.

1. The Problem

19th Century was a period where indigenous populations of the southernmost extreme of America ("Yamana") faced the impact of European and North-American hunting of whales and sea lions. Industrial hunting was so intensive that by the beginning of 19th century, the total number of hunted preys began to decrease, arriving to a nearly extinction by the end of the century. Obviously, the continuing decrease of the most important resource affected to indigenous populations.

In this paper we are not discussing the historical consequences of these events, but we want to study the reliability of the frequency seriation assumption in the archaeozoological case: the relationship between the similarity in date (or stratigrafic ordering) between assemblages and the similarity in proportions of different bird species. The idea is to know if the relative ordering of assemblages follows a chronological sequence, and if the global variation of proportions and/or absolute frequencies can be interpreted as an increase or decrease in consumption of birds.

If we understand animal bones found in archaeological contexts as an accumulation of garbage after food processing and consumption, then the variable proportions of bones can be studied as an evidence of the frequency determined animal was processed and consumed. Our unit of analysis is the accumulation of bird bones, which should be understood as aggregates of discarded elements. This kind of problems has been analyzed in archaeological literature as "assemblage diversity through time" or "frequency/diversity seriation" (Djindjian 1990, Baxter 2003). The idea has been that of converting a longitudinal record of archaeological accumulations into a coherent event history, or site formation process. The concern is the simple description of changes in values of variables over time.

A.L. Kroeber used frequency seriation for the first time in 1916 to measure the passage of time. It has been traditionally defined as a relative dating method which relies principally on measuring changes in the proportional abundance, or frequency, observed among finds. Assuming that artefact characteristics follow a bell curve of frequency, starting slowly growing to a peak and then dying away as other characteristics becomes more frequent provides the basis for frequency seriation. This also assumes that descriptive features will be broadly similar from assemblage to assemblage within the same time span. Following these rules, an assemblage of objects can be placed into sequence so that sets with the most similar proportions of certain characteristics are always together.

Traditional frequency seriation is based on the wrong assumption that archaeological accumulations should be considered as distinct chunks of time. However, archaeological accumulations are aggregates of time, variables rather than units of analysis. They may be used to delimit the cases for analysis in a particular study, but they are not themselves typically employed as units of analysis. Therefore, it should be assumed that we are analysing a single entity across time, and not different entities at a specific moment of its history.

Another way of dealing with seriation is the examination of changes, not in the values or levels of variables over time, but in relationships between or among variables over time. It is one thing, for example, to say that bird exploitable biomass has been increasing for a century. It is another to indicate that in the early stages of the site, hunted and processed bird biomass declined, but in later stages, other factors were responsible for an increase in the capture and consume of birds. In other words, frequency/diversity seriation serves two primary purposes: to describe patterns of change, and to establish the direction and magnitude of causal relationships.

In its simplest form, an event history is a longitudinal record of when events happened to a sample of individuals. Assuming that an event consists of some qualitative change that occurs at a specific point in time, we may consider archaeological events in terms of strictly differentiated archaeological deposits or assemblages. In our case, we are studying a single human community who occupied the same place at different – not necessary contiguous moments – which hunted, processed and consumed birds, among other local resources. The analysis involves some comparison of data between or among periods, not necessary contiguous.

Our analysis should be understood as an assemblage diversity comparison, where data are counts of the occurrence of class i (bird bone of the ith species) in assemblage j (each one of the j stratigraphic episodes). The assumption is that variability in bird hunting and processing can be expected to lead to differential representation in archaeological assemblages of different taxa (Baxter 2001, 2003).

Single accumulations or assemblages have measurable characteristics, some of which are inherently aggregate in nature (size, composition) and others are summations or averages of the items included in the assemblage (Minimum Number of Individuals, Biomass estimations). By contrast, we do not measure aggregate characteristics of accumulations, as such, but we measure aggregate characteristics of a class of elements (discarded carcasses of birds) during a particular period

Variability in aggregate characteristics of archaeological accumulations is, however, subject to a number of factors. Such factors can affect the relative frequencies of bones in an assemblage, and determine variations and diversity between periods. To understand this variation, it is assumed that the frequency and diversity of items within an assemblage vary according to the process responsible for the accumulation. The main necessary assumptions are:

- garbage disposal is a random accumulation around the residential and/or domestic unit,
- the nature of the accumulation does not change for all the history of the site,

then,

- the amount of residues accumulated in a single event depends on the number of people generating garbage, the time during which they have been producing garbage, and the social way of disposing garbage (Varien and Mills 1997, p. 143).

However, bone frequencies and diversity are affected also by the relationship between element use-life and time. Schiffer (1987: 55) labels the problem as the "Clarke Effect" to describe "the statistical tendency for the variety of discarded artefacts to increase directly with a settlement's occupation span". This principle indicates that previous assumptions are over specific, and that real archaeological data do not follow them. Artefact use-life, differential temporal duration and the different nature of accumulations within the same site formation process can (1) produce variation in assemblage composition that might be erroneously attributed to different activities, (2) affect seriations in non-chronological ways, and (3) cause archaeological frequencies to differ from systemic frequencies.

To address the problem posed by the Clarke Effect, we have examined some determinants of differential temporal duration. We regard bird bone assemblages as the interaction of temporal duration and stratigraphic order. An alternative would be to assume some characteristic or set of characteristics associated with the assemblage that produced the apparent accumulative effect. The problem then becomes one of identifying the appropriate characteristic or set of characteristics of the accumulation, a theoretical rather than a methodological problem.

ASSEMBLAGE = PERIOD (stratigraphic order) – DURATION

2. The Data

Túnel VII is an archaeological site located in the Beagle Channel (Tierra del Fuego. Argentina). It is a shell midden, and should be understood in terms of garbage produced and accumulated by some group of people during a determinate interval of time. The excavated site represents the history of a single hut, used by a group of fisher-gatherer and hunters during a limited period during 19th Century, based on dendrochronology and the presence of imported European items. The group was probably composed of single a family, which moved frequently from location to location looking for locally available firewood and other coastal and marine resources (Estevez and Vila 1997, Estevez , pers.com). More than 5000 bird bone remains have been studied and classified anatomically and taxonomically in several categories (Penguin, Cormorant, Big Sea Birds, Small Sea Birds, Coastal Birds, Terrestrial Birds and Raptors). Additionally, bone remains have been investigated for the presence/absence of butchery marks. Using low resolution microscopes (x20), different types of marks were described and quantified (Mameli 2002, 2004, Mameli and Estevez 2004). This study integrates as "butchery marks" all kinds of chopmarks, cutmarks and scrapings.

Different stratigraphic units have been identified during fieldwork. Each stratigraphic unit corresponds to a single deposition of residues. Ethnology tells us that each occupation at a single location was always very short (days or weeks), but frequently people came back at the same place, although not necessary in annual cycles (Orquera and Piana 1999). The same place could be occupied each season, or the site could be abandoned for a long period of time. Stratigraphically related single depositions have been integrated into temporal layers. Nine layers have been identified, the first one without bird

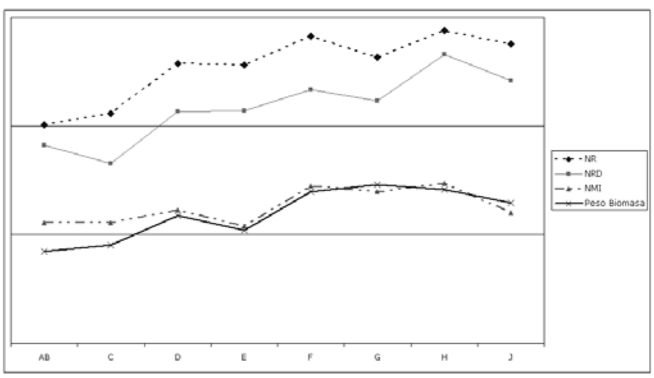

Fig. 1. Variability among different quantification units (NR=NSP; NRD=NISP; NMI; Peso Biomasa= Biomass estimation).

remains, so we have limited our analysis to a frequency seriation of bird bones in 8 temporal stages: B,C,D,E,F,G,H,J (from the oldest to the newest).

3. Frequency Seriation

A preliminary inspection of data and their stratigraphic ordering has been used in order to look for a general trend in the total frequency of hunted/processed birds, using different estimations for bird frequencies (NISP, NMI and biomass, cf. Mameli 2004). Parametric and Non-parametric correlations, suggest that all quantification units are comparable.

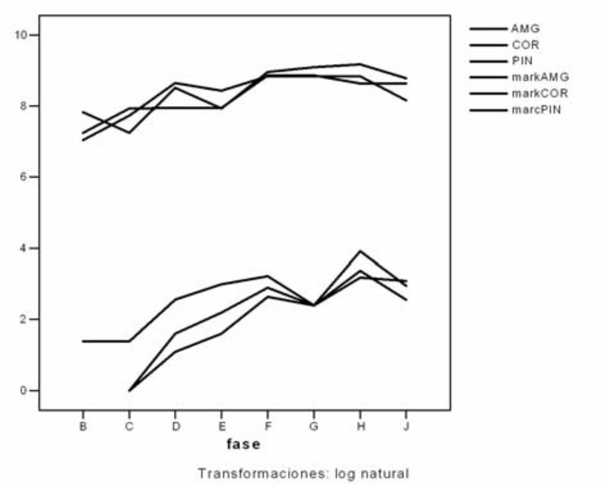

Fig. 2. Seriation of log-transformed biomass estimations and absolute number of bone rests with butchery marks, for the dominant species (AMG= Big Sea Birds; COR= Cormorants; PIN= Penguins). Lines at the upper part of the graph represents biomass estimations, and lines at the bottom are for the number of marked bones.

A preliminary inspection of data suggest that Yamana people increased through time (stratigraphical ordering) the quantity of hunted and processed birds. If we concentrate the analysis on biomass calculations, minor proportional differences among the three main taxa (Big Sea Birds – albatross –, Cormorants and Penguins) do not hide the existence of a strong linear trend. A relatively similar linear trend exists when we consider the absolute number of bone rests with butchery marks.

It can be proved that the higher the NISP, the higher the absolute number of bones with marks.

If we consider time by time ANOVA results, F-values are significant in all cases (both at the level of NISP, biomass and the number of bones with marks). In the case of NISP and biomass estimations Post-Hoc tests based on Tuckey and Scheffe contrasts identify non-significant differences only between contiguous periods in the case of biomass estimations: B and C, D and E, F and G, G and H, H and F. In the case of bones with butchery marks, ANOVA gives a non-chronological seriation of assemblages: B, C, [D, H, G, J], [E,F,H].

However, we cannot assume equal variances among temporal layers. When using other measures of association which are not based on the assumption of equal variances (Tamhane T2, Dunnett T3, Games-Howell, all of them based on t-test), only differences between F,G and H are non significant. This result suggests, that differences of variance between all 8 assemblages affect decisively in measures of contiguity, and hence, on frequency seriation. We should investigate on the factors explaining variance differences among temporal layers.

4. Seriation Through Multivariate Analysis

Correspondence Analysis has been used extensively to detect the existence of serial correlation among the data, and its explanation in terms of temporal ordination (Djindjian 1990, Baxter 2003).

A Correspondence Analysis of biomass estimations gives the following result (75% of total variance explained by two main dimensions).

Fig. 3 shows evident traces of horse-shoe effect, where the older (B) and the newer assemblages (J) appear at the extremes, but very near. The pattern has some circular linearity, but it cannot be explained in historical terms. We must be certain that duration is entirely irrelevant, or include duration as an explanatory variable, or control duration by making duration specific comparisons. To be able to study changes over time, we should be capable of separating duration, period and accumulation effects. Typically, this will mean either ignoring accumulation effects or representing them in terms of assemblage characteristics, such as size.

We can approximate temporal duration in terms of occupation span. This has been done by counting the number of single deposition events at each temporal layer or episode, and the total excavated volume from each temporal layer. There is a perfect linear relationship between number of single depositional events and the total volume of accumulation, except for temporal layer F, the episode with the most number of depositional events but with a low volume of accumulation.

In order to analyze the multidimensional contribution to the seriation pattern, we have calculated different analysis using the following variables: volume of accumulation, number of occupations, NMI estimations, NISP estimations, Global

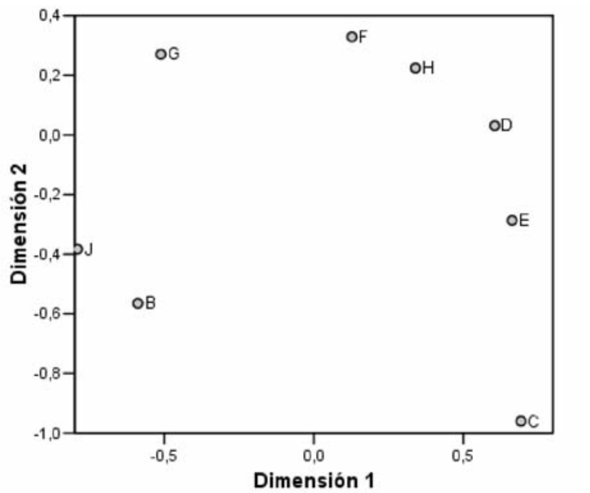

Fig. 3. Correspondence Analysis for the differences in Biomass estimations between the nine archaeological episodes.

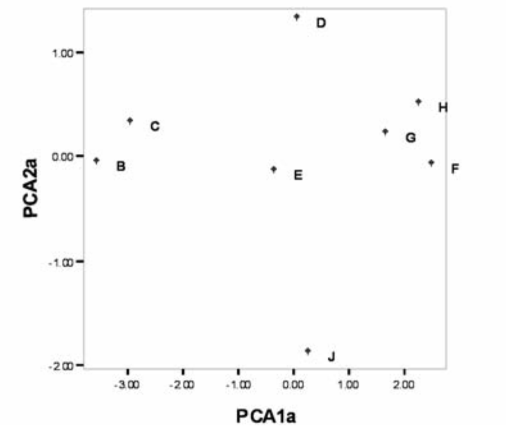

Fig. 4. Principal Component Analysis for the log-transformed variables: volume of accumulation, number of occupations, Total NMI, Total NISP, Total biomass , Average of Bones with butchery marks, Big Sea Bird biomass estimations, Cormorant biomass estimations, Penguin biomass estimations.

biomass estimations, Average of Bones with butchery marks, Big Sea Bird biomass estimations, Cormorant biomass estimations, Penguin biomass estimations. Original raw data have been transformed in order to equalize scales of measuring, using logarithms and/or subtracting the mean. Multidimensional calculations have been carried out using Principal Component Analysis and Non-Metric Multi-dimensional Scaling. Results are very similar in all cases. We present here those corresponding to PCA with log-transformed data. A multidimensional solution in 2 Dimensions, explains 85% of total variance. All variables have positive correlations with First Dimension (explaining 73% of variance), whereas only Volume, Global NMI and Cormorant biomass estimation have positive correlations on the Second Dimension (explaining 12% of variance).

The results are very similar to time by time ANOVA. Oldest temporal layers are strongly associated, in terms of quantities of bones and temporal duration. The same is true for layers F, G, H, with higher numbers both in temporal duration and quantities of bones. Layers D and J are the most dissimilar, J being a very short layer, but with an important amount of birds, and D, a very long occupation, relatively poor in bird remains.

Episode E, in the middle of the sequence, is also placed in a central situation according to duration and quantity of birds.

5. Looking for a Historical Trend

It is important to take into account, that in this case occupation span is not correlated with stratigraphic order, what means that temporal duration does not increase through time, because there is a considerable diversity in the nature of each temporal layer. This heterogeneity increases, if we consider the volume for each single deposition event within each temporal layer. If we average quantity estimators (biomass and NISP) using temporal duration ones (volume of accumulation), and we calculate the ratio of biomass and NISP for volume unit (biomass/volume), a strong non-linearity appears. Averaged data have been log transformed for comparability.

Results are very similar to those of non averaged data (Fig. 1 and 2) except for the high values we obtain now for J: a short temporal layer, but with a relative proportion of birds greater that in previous but longer layers.

If we read biomass averages per temporal duration in terms of sistematicity of bird hunting, then we can explain the global series (sumation of biomass estimations for all taxa) as three different qualitative moments: low sistematicity (B, C, D), suggesting that hunting is only marginally oriented to bird capturing and processing, medium-high (E, F, G, H), and very high (J). These results coincide more or less with Principal Component Analysis, and show that local economy changed progressively into a more systematic approach of bird resources. Absolute numbers of discarded bones are a consequence of this general trend.

To better describe change through stratigraphic ordering we have calculated the percent of raw change, calculated as 100%(x2–x1)/ x1.

This calculation measures the percentage gain through time. Although we have seen that biomass increase through time, biomass gains from period to period are not stable. That means that the rate of change is discontinuous: relevant changes should be placed at periods E (important increase in “degree of sistematicity”), H (decrease) and J (increase).

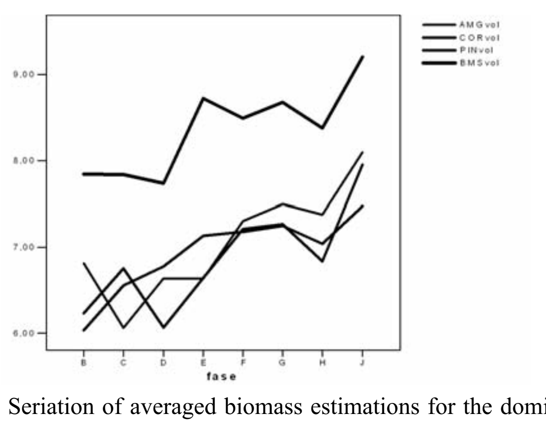

Fig. 5. Seriation of averaged biomass estimations for the dominant species (AMG= Big Sea Birds; COR= Cormorants; PIN= Penguins; BMS: total biomass estimation). Lines at the upper part of the graph represents biomass estimations, and lines at the bottom are for the number of marked bones.Data have been averaged by volume of sediment.

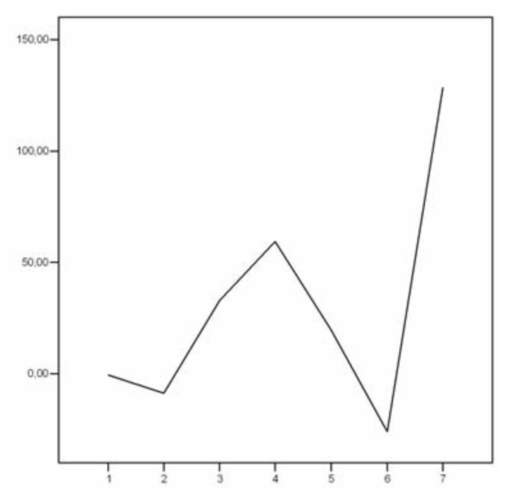

Fig. 6. Seriation of percentage gains in biomass, averaged by volume of sediment.

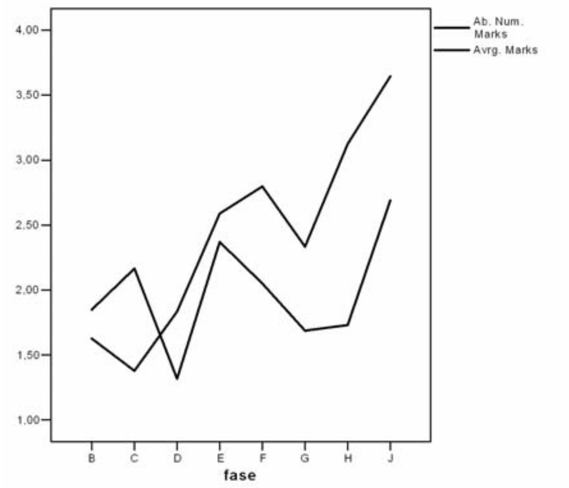

Fig. 7. Seriation of the averaged absolute number of bones with butchery marks (by volume of sediment), and seriation of the average number of bones with marks (also averaged by volume of sediment).

Consequently, we cannot conclude a uniform increase in the average number of birds captured, processed and consumed by temporal duration unit, but a non linear and non monotonic increasing trend, punctuated by some moments of decrease. Speaking of "periods" and not of "layers", we can say that bird consume reduces when we pass from period B to period C. It experiments an important increase after period C, until period H, which should be interpreted as another moment of reduction in bird processing. Final moments experiment a strong recuperation, more intense than in previous moments.

When we take into consideration the number of bones with butchery marks, there is a similar non-monotonic increase, but when considering the average of bones with marks within each temporal layer, the series loses any trace of serial correlation nor temporal seriation. Averaged data have been log transformed for comparability.

These two opposite trends can be explained in terms of the consequences of a change towards a more systematic capture of birds – the higher the number the captures, the higher the number of bones with butchery marks –, but also in terms of the lack of a tendency to intensify the exploitation of obtained preys. Yamana people hunted more birds for consuming them, but they do not changed their way to process them. We may note some peculiarities. In period C: an increase in the average of bird bones with butchery marks, coincide with a net decrease in bird biomass (specially Big Sea Birds), suggesting in this case that less preys were more intensively exploited. The same may be true for period D and H. This irregularity or inconsistency in intensification of bird processing should be explained not in terms of the number or average of bones with marks, but on additional characteristics of marks (see Mameli 2004). That means that the increase in the total number of hunted and exploited birds at the site is not correlated with an increase in the intensity of consumption. It has been suggested that in moments of scarcity, food is obtained by increasing the capture of less profitable resources (birds, as compared to sea mammals), but also by augmenting the usability of processed materials. That means that in conditions of scarcity, bird bones should be processed until the exhaustion of any profitable meat or fat. This action should leave important use-wear on the bone surface. Detailed quantitative studies show, in the Túnel VII site, that although sea mammals resources decrease through time, and birds are being captured as a partial alternative, birds were processed like in previous periods, without suggesting an increase in the quantity of substance extracted from the bones and skeletal parts.

In any case, it may be suggested a general trend towards an unification of bird processing, given that the main three taxa show at the end of the studied period similar averages of bones with butchery marks.

6. Conclusion

In this paper we have investigated how frequency seriation can be misleading, because it does not render correctly temporal evolution. It is impossible to render time with just only stratigraphic order, without taking into consideration the existence of linear trend and/or the different temporal duration of episodes. We have discovered a consistent temporal trend in the general increase in bird hunting, both at the NISP and Biomass level. There is strong linear correlation between the quantity of data and stratigraphic ordering. The differences in temporal duration between temporal phases increase the nonlinearity of the series, without masking the serial correlation. Therefore, we can suggest an historical trend characterized by the growing of exploitable biomass by hunting the most profitable birds available (in terms of biomass) and not increasing the number of individual preys from other taxa.

There is not a consistent temporal trend in the average of bones with butchery marks. The total number of marked bones increases because bird hunting has increased through time, but preys are not being processed differentially.

Furthermore, statistical results show that the longer the temporal duration of an episode, the more single deposition events, and the more biomass from bird will be used and the more bones will show butchery marks. It seems as if the longer the occupation, the more evidences of bird hunting and processing (Clarke Effect). There is a possibility that serial correlation detected by Correspondence analysis is a consequence of linear trend in the total number of bone sherds (NISP). That means that instead of a historically significant trend Correspondence Analysis results are based on the quantitative differences in the total number of bone fragments between the oldest and the newest occupations. To remove this possibility, we have integrated all quantitative estimations and temporal estimations in a single multivariate analysis. This strategy allows the differentiation of assemblages on a more detailed basis.

We should conclude then that most variation between temporal episodes is due to the different nature of each occupation, and to differential temporal duration.

The fact that the site was continually reoccupied by the same population implies that something about the past of the series is likely to remain fairly stable. It need not be the time series itself, but is must be some function of the time series that remain unchanged with time. This stability is precisely the component which ensure continuity. Without some kind of assumption of stability we can do nothing logical about explaining history. That means that some degree of determinism should exist. We have seen that successive episodes have more in common than episodes not temporally contiguous. That means that the remote past is not as good a predictor as the recent past, and that our ability to predict an event is best nearer the event, and worsens as we recede from it.

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