CASE HISTORY OF THE PERU PREDICTION FOR 1980-81

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1. THE PREDICTION AND ITS DEVELOPMENT

The prediction that a massive (M_w = 9.0) thrust-fault earthquake would occur in 1981, in the coastal region of central Peru, began in 1976 as a forecast formulated at about the same time as, and which attracted much less attention than, others that were investigated (Cape Yakutaga, Oaxaca, Nicaragua), probably because they were based on the generally-accepted empirical paradigm of the seismic gap (Spence 1979). The author of the forecast for Peru is Dr. Brian T. Brady, (M. Sc. Geophysics, M.I.T., 1964; Ph. D. Applied Mathematics, Colorado School of Mines, 1969) employed from 1967 to the present, by the United States Bureau of Mines, as Supervisory Physicist. He is the author of more than forty scientific publications in respected and well-known journals. His research experience includes studies of rock fracture, physical processes involved in earthquake development and in producing plate motions.

In September 1976, a conference on "Global Aspects of Earthquake Hazard Reduction" held in Denver, Colorado, USA, was attended by 32 well known scientists from 11 institutions, including Dr. Brady. The meeting report was prepared by Drs William Spence (meeting convener) and L.C. Pakiser, both with the U.S. Geological Survey Office of Earthquake Studies. Brady's presentation described microscale characteristics of rock failure and suggested that the process is scale-invariant. He showed that data for precursor time versus fault length plot linearly from the scales of laboratory failure and mine rock bursts to the scale of major earthquakes. These data lead to the important conclusion that the physical basis for earthquake occurrence may be very similar to the mechanics of rock failure in mines or in the laboratory. The meeting report includes a reference to Brady's paper "Theory of Earthquakes, IV, General Implications for Earthquake Prediction" published in Pure and Applied Geophysics in 1976. This paper discusses the earthquake sequence that occurred approximately 60 km off the coast of Central Peru, between 3 October and 9 November 1974, within a well-documented seismic gap, and suggests that it could have important seismological and sociological consequences. His arguments led to the possibility that the

region in question, between 11.5°S - 14°S and 76°W - 79°W, might have again approached a critical state and be in the process of preparation for an earthquake of magnitude at least M8.2. Brady goes on to state that if there were no further destressing seismic events then the precursor times for a range of predicted magnitudes of 8.2, 8.3 and 8.5 would be 7.1 yr, 8.9 yr and 14 yr, respectively, measured from November, 1974. It is important to note that Brady also stated that the hypothesis could be tested by detailed monitoring of sea-level changes, anomalous Vp and/or Vp/Vs, radon emanations, possible secular variations in the geomagnetic field and seismicity.

We received at the Instituto Geofisico del Peru (IGP) and CERESIS the reprint of Brady's paper from Dr. William Spence of the United States Geological Survey (USGS), in late 1976. It was highly unlikely that anybody else in Peru would have known at the time of Brady's article in Pure and Applied Geophysics; we believe that only six persons in Peru, (Casaverde, Deza, Giesecke, Huaco, Ocola and Silgado) were aware of the forecast.

We began corresponding with Dr. Brady immediately. We questionned the completeness and accuracy of this data base, the applicability of the Utsu relationship between aftershock area and magnitude and his selection of certain precursory events on which he based his calculations to arrive at the specific date for the main event.

As a result of the Denver Conference, held in September 1976, Dr. L.C. Pakiser, at the time acting chief of the Branch of Seismicity and Earth Structure of the US Geological Survey, and Dr. William Spence, requested Brady to update his studies of the Peru seismicity. Brady's report to Dr. Pakiser, dated 25 August 1977, reiterated his belief that a serious situation had developed near Lima, since November 9, 1974, and that supportive data, including theoretical studies, led him to estimate the epicenter (12.5°S, 77,7°W) magnitude (M8.4 $\pm$ 0.2) and minimum preparation time measured from 14 November 1974 (5.9 years), i.e. circa October 1980. We do not know how this report was circulated officially but many people in the USGS had a copy. In fact, copies of this report and of other internal USGS documents apparently were readily available to outsiders; some were reproduced and published in the Lima newspapers in 1980 and 1981. At the Geophysical Institute and at CERESIS we decided that we should treat the prediction with the utmost reserve and do our best to monitor at least some of the Class 1 precursors that have been observed prior to major earthquakes.

In view of Brady's report to Dr. Pakiser, I informed the U.S. Ambassador in Lima of the predicted earthquake to occur in or about 1980/81, and requested his support to propose a meeting with experts of the USGS. Dr. Robert Hamilton, Chief of the Office of Earthquakes Studies of the USGS, in Reston, Virginia, who knew of Brady's forecast, which he considered "far-out", kindly arranged with Dr. Pakiser to convene a meeting in Golden, Colorado on 18 November 1977, a date on which I was able to attend. There was relatively little discussion of the theory but nevertheless my impression was that most of those present agreed that it had scientific merit. The accuracy of the location of the seismic events selected by Brady as precursors for his forecast was questioned and it was agreed that the epicentres should be recalculated. We were informed by Dr. Pakiser that Brady's report has been submitted to the Earthquake Prediction Panel of the USGS for evaluation, as well as recent results from Dr. Spence and Brady, supporting the prediction. The Panel had not responded, very likely because the prediction was for a foreign country. Dr. Robert Wallace, of the USGS at Menlo Park, who was present at the meeting, commented that if the Brady prediction were for the United States, the USGS and others would be working quite seriously to determine its validity. At my request, Dr. Brady agreed at the time not to publish any paper that would further support his prediction, without prior approval by the Peruvian Government.

The Minister of Education, on whom IGP depends, was kept verbally informed of developments from the beginning. He asked for a written report in August 1978, for him to present to the President. In that report I stressed the importance of additional funding for IGP to enable it to carry out a programme to detect and identify precursors, regardless of the degree of credibility given to the Brady prediction. However, no additional funds were allocated at the time.

Early in 1979 Dr. Brady told me that his latest results confirmed his belief that his prediciton was more correct than not. I requested Dr. H.W. Menard, Director of the U.S. Geological Survey in Reston, Virginia, to agree on a joint meeting of USGS and IGP seismologists. The Oaxaca, December 1978, event took place in an identified seismic gap had reinforced our concern about the credibility to be given to predictions. Dr. John Filson, on behalf of Dr. Menard, agreed to a meeting on 24 May 1979, in Golden, Colorado "to review and discuss matters related to earthquake prediction and hazards in Peru". It was understood that the USGS would not, as a result of the meeting, formally endorse, condemn or other wise indicate any official evaluation but would assist IGP in the assessment of

the current status of earthquake prediction research and its relevance to Peru. Dr. Brady was invited to present the latest results of his earthquake research.

The month before we met in Golden, the International Symposium on Earthquake Prediction was held in Paris, on 2-6 April 1979.It is interesting that there was no mention of the Brady prediction for Peru in any of the papers nor by the experts invited by UNESCO to evaluate the Symposium and to discuss social and economic aspects of earthquake prediction, during the following week.

The meeting in Golden on 24 May 1979 was attended by 15 scientists: 9 from the USGS, 4 from IGP, 1 each from the Bureau of Mines and the Carnegie Instituteion of Washington; also present were representatives of the Office for Foreign Disaster Assistance of the U.S. State Department, the Bureau of Mines and the Peruvian Ambassy in Washington.

In the course of his presentation Brady made the formal prediction that in September 1980 a foreshock series would begin and would last about nine months, with a sequence of 13 events; the mainshock would take place in July 1981, magnitude M_W 9.8 (7×10^{26} ergs), with a rupture from 12.5°S latitude to 24.5°S, off the coast of Peru and Chile. This shock would be followed by another large shock in April 1982, M_W 8.7, rupturing from 12.5°S to 8.5°S. This formal prediction was based on two lines of argument. In Brady's own words, the first relied solely on the observed seismicity patterns in central Peru and his interpretation of those patterns with his theoretical model of the failure preparation process in rock materials. The model was, and continues to be, in the developmental phase. The second argument was based on the plausibility of major decoupling events along the Peruvian and Chilean coasts (approximately 7°S - 28°S). The plausibility arguments (geological, geophysical, space-time seismicity patterns during the 1974 sequence) were developed jointly by Spence and Brady. That phase of the investigation was undertaken in response to Brady's theoretical arguments that the offshore zone had approached a critical state. The plausibility arguments remain plausible as they are obviously independent of any theoretical model. Spence argued that there is strong coupling between the Nazca and South American plates and offered evidence against a seismic slip; others like H.W. Dewey, who have analyzed the potential for a massive thrust-fault earthquake in the region of Brady's prediction from the seismic gap point of view, come to the conclusion that such an earthquake is most unlikely to occur in the next decade, based on evidence that supports the

assumption that much of the motion of the South American plate relative to the Nazca plate is accomodated by aseismic deformation. Dewey did not consider Brady's prediction in terms of its theoretical model of precursory phenomena.

Brady was challenged because he was reminded that the scientific community requires publication in such detail that other researchers can replicate results and derive the same conclusions, based on equivalent data sets, replication of results being essential to validation, acceptance and use of a prediction model.

Both Brady and Spence informed the meeting that a complete analysis of the data leading to the prediction was in preparation and that a report would be ready by September 1980, to be published should the predicted foreshock series begin; Brady stated that he had not published his work bearing in mind IGP's request, at the prior meeting in November 1977 meeting, that he not do so. The meeting report which IGP presented to the Government of Peru stated that the majority of those present remained unconvinced that Brady's prediction was valid, but nevertheless it stressed the importance of improving IGP's capability to monitor and interpret precursory phenomena.

Because the first of the primary foreshocks gave only a ten-month lead time before the main shock, it became important that a comprehensive programme to gather a wide range of precursory data, in terms of the inclusion theory of earthquakes, be ready to implement by September 1980. In a private communication dated 26 October 1979, Brady and Spence refer to two developments that increased the probability of occurrence of the predicted earthquake: (1) the "El Centro" (California) earthquake, forecast by Brady during an OES Seminar in Golden, on 11 May 1978, and again during the 24 May 1979 meeting with IGP, which did occur in the target area (Salton Sea), with a magnitude and on a date compatible with the forecast, and (2) the independent finding by Dr. V. Kulm of Oregon State University of major subsidence on the Peruvian continental shelf between about 11.8°S and 13.5°S of some 500 meters in the central portion increasing to about 1,000 meters, there being no evidence of either subsistence or uplift north or south of this zone. Kulm thought this subsistence to have occurred near the end of the last five million years, a time consistent with Brady's theoretical preparation time for the predicted 1981 earthquakes. In the same communication Brady and Spence outlined what they considered to be the most relevant measures that should be carried out to permit a continuing evaluation of the prediction status and stressing again that a critical part of the

prediction was the foreshock series to begin about September 1980.

CERESIS, with financial aid from Unesco, UNDRO and UNEP, organized a Regional Seminar on Earthquake Prediction and Seismic Risk. It was held in San Juan, Argentina, in October 1980, hosted by INPRES. Brady's prediction might have influenced the UN agencies in their decision to fund the seminar, which was well attended by scientists from all over the world. Dr. Brady and Spence presented a paper on the Peru prediction which the news media publicized. On the other hand, the scientists were not excited and their formal discussion of the Peru prediction was rather perfunctory. One of the participants at San Juan was Dr. Clarence Allen, President of the U.S. National Earthquake Prediction Evaluation Council (NEPEC), which was established to evaluate predictions affecting the United States. I asked Dr. Allen if NEPEC would evaluate the Brady prediction should the Peruvian Government request it; Dr. Allen replied that in the view of the circumstances NEPEC would probably make an exception and accede.

We arranged for Brady, Spence and other participants to visit Lima, Peru after the San Juan seminar. Private meetings were arranged with the President of Peru, Arq. Fernando Belaunde Terry, and the U.S. Embassy. President Belaunde, after listening to Brady, Spence and others, was not convinced that an emergency situation had developed and concluded that Brady's prediction did not increase the probability for the occurrence of a very large earthquake as compared to Peru's "normal" probability of such catastrophes. He agreed that it was logical and necessary that IGP do its best to monitor precursory evidence and asked me to act on behalf of the Government with regard to possible assistance from the United States Government including a request to NEPEC for an evaluation of Brady's prediction; I did so on 25 November 1980. NEPEC met on 26-27 January 1981. NEPEC claims that its work was hampered by the fact that no recent paper setting forth Dr. Brady's theory, model of current status of his prediction was available to the Council members for review; furthermore, one and a half days were insufficient for comprehensive follow-up of lines of questioning by Council members, particularly on the theoretical basis of Brady's prediction or the complex mathematical formulations on which his model is based.

The members of the Council were unconvinced of the scientific validity of the prediction. The Council stated that it had been shown nothing in the observed seismicity data or in the theory, in so far as presented, that lent substance to the predicted times, locations and magnitudes of the earthquakes. The Council

recommended that the Government of Peru not give serious consideration to the prediction, although it could not, of course, state with complete confidence that major earthquake could not occur at the predicted times, but that such probability was very low indeed. The U.S. Geological Survey endorsed the conclusions reached by the Council.

NEPEC's official report to the Peruvian Government was made public to the press in general. Coverage in the Lima papers was not impressive, although Government spokesmen, including President Belaunde, expressed their satisfaction with NEPEC. The journal "Science", in its issue of 20 February 1981, had an article entitled "Prediction of Huge Peruvian Quakes Quashed", and several foreign newspapers carried the news.

The Council's pronouncement did not, of course, reduce the earthquake hazards in the region. Dr. Brady held steadfastly to his prediction and continued to do so not out of hubris, or obstinacy, but out of a moral conviction that there was a large enough chance that he was right and that people should be forewarned.

On 14 August 1980 an M_L4.0 event was detected in the expected foreshock area. Sixteen additional events were recorded with magnitudes ranging from M_L3.0 to M_L4.5 up to 10 April 1981; one of them on 20 September 1980. As this sequence developed, Brady believed that the overall characteristics of the final foreshock phase were occurring as indicated by the prediction.

Between October 1980 and May 1981, a large number of earthquakes occurred in Ayacucho (central Peru, inland), which caused loss of life and considerable damage in rural areas. These were superficial events with magnitudes of the order of M5.0. Brady identified this activity as coinciding in time with the predicted foreshock series in the nucleation zone but IGP publicity reported that there was no evidence which related Ayacucho to Brady's prediction area. However, the prolonged seismic activity in Ayacucho gave rise to speculation in the news media.

Brady's status report dated 7 May 1981, to Dr. Moravelli, Director, Division of Minerals, Health and Safety Technology of the Bureau of Mines, specified preliminary dates, subject to change as additional data from the Peruvian seismic network became available, for three large predicted events: the first to occur on or about 6 July 1981, with a magnitude M_W8.1-8.3, the second, on or about 18 August, M_W9.2, and the third on or about 24 September, M_W9.9 +. A memorandum dated 19 June 1981, directed to Dr. John Filson, Head of the Office of Earthquake Studies, confirmed Brady's prediction that the mainshock was to occur between 26 June and 30 June 1981.

However, in a letter dated 28 April 1981, Brady informed me that the first large event would occur on 28 June 1981, and not on or about 6 July; should it not occur he would withdraw the prediction. While convinced that the area affected by the predicted shocks is capable of sustaining earthquakes of the predicted magnitudes and that the Nazca and South America Plates are locked between the latitude limits of 7°S to 28°S, Brady also stated he would remiss in not conveying his reservations concerning the validity of the prediction. He was convinced that the space-time off-shore seismicity patterns were real and conformed to his theory but that this did not prove that the theory was correct and that large earthquakes would occur. Whether those patterns were unique or just random fluctuations remained a question of conjecture at the time. Although Brady personally believed his prediction was correct, his letter was useful to indicate the uncertainty of the prediction.

In late May 1981, Dr. Spence officially announced that he believed Brady's prediction to be incorrect and that none of the earthquakes, as predicted, would actually occur. The main reasons for his disavowal were: (1) only one of the foreshock series between October 1980 and May 1981 was actually located exactly in the target zone; (2) the second foreshock series to begin in mid-May 1981, (teleseismically detected) did not occur; and (3) numerous low-magnitude seismic events, recorded by IGP in or near the target zone, were quite likely representative of continuing long-term, low-magnitude seismicity characteristic of the region near the boundary between the Nazca and the South American Plates and thus the uniqueness of the activity detected could not be demonstrated. If no earthquakes occurred that could more confidently be interpreted as foreshocks then the prediction of the mainshock (s) could effectively be considered withdrawn. Furthermore, independent

evidence of geophysical anomalies that could be construed as precursors as not reported by IGP; given the size of the predicted earthquakes, such anomalies should have been quite evident. Spence recognized that there remained considerable evidence for a high, present-day seismic risk throughout the zone of the predicted earthquakes and, in particular, he considered southern Peru and northern Chile as a region of very high, present-day seismic potential. He concluded by stating that he did not doubt Dr. Brady's sincerity and that he appreciated the stimulating effect of a creative scientific mind, such as Brady has. However, he reluctantly realized Brady believed too much in the correctness of his prediction to function self-critically in assessing the relevant seismic data.

The press was not informed by IGP or other Peruvian government agencies of Brady's status report of 7 May 1981 to Dr. Moravelli, or his letter to me of 18 April 1981. Nevertheless 28 June 1981 was soon known by the public as a date for the predicted mainshock.

Fortunately the earthquake did not occur and I can end this aspect of the prediction by referring to a letter from Dr. Brady to me, dated 20 July 1981, in which he recognized that his prediction of the large seismic events off the coast of central Peru, as presented at the NEPEC meeting in January 1981, was incorrect. Without the occurrence of the first large event, on or about 28 June 1981, which would initiate the decoupling process between the Nazca and South American Plates, the probability of the occurrence of the two remaining large events became exceedingly low. Dr. Brady concluded by saying that he was greatly relieved that his interpretation of the space-time seismicity patterns in central Peru was not correct.

2. GOVERNMENT RESPONSE TO THE PREDICTION

2.1 Government of Peru

As has already been indicated, government geoscientists in Peru knew of Brady's forecast and subsequent prediction in 1976. It gave rise to a sequence of events which lasted approximately five years. The responsibility for action in response to such knowledge, at least during the first three years, fell on the Instituto Geofisico del Peru (IGP) and CERESIS. The Minister of Education was given

copies of pertinent correspondence and scientific reports, starting in 1977, because of the potential social and economic implications of such a catastrophic prediction, regardless of its scientific validity. The Minister concurred with our view that the matter should be handled confidentially. At his request, during the second semester of 1978, we informed the highest authorities in the Ministry of Foreign Affairs, the Institute of Planning and the Executive Secretariat of the National Committee for Civil Defence. It was not until 9 November 1979, that I was asked to make a formal presentation of the situation, at Civil Defence Headquarters, to the Vice-Ministers and the Directors of all government agencies, including the Red Cross. The meeting had two objectives. First, to decide on a reasonable commitment, in terms of government funding, to improve IGP's capability to detect and interpret the expectable precursory phenomena, bearing in mind that, regardless of the Brady prediction, such an investment was logical in the light of Peru's high seismic hazard; and second to learn the state of preparedness in the relevant sectors of government and to decide on priorities for what needed to be done.

The group endorsed a strong recommendation to the President and his Cabinet to allocate about one million dollars to the IGP. As to the state of preparedness for disasters in general, much had been accomplished with very modest resources. Civil Defence was created in 1972 to cope with vulnerability and risk analysis, planning and implementation of protective measures prior to a disaster and relief operations after the disaster, including, besides earthquakes and tsunamis, landslides, avalanches, inundations, electrical storms, explosions, pollution, fire, drought and others. Civil Defence has a Scientific Advisory Committee and a small technical staff, but it is able to call for and co-ordinate action of military and relevant civil agencies.

Soon after the meeting at Civil Defence on 9 November 1979, there was a marked increase in newspaper space dedicated to the possibility that a major earthquake would hit Lima by 1980. The large number of people present at the meeting made it impossible to continue treating the Brady prediction as a confidential matter.

Early in 1980, American consultants at the Instituto Peruano de Energia Nuclear (IPEN) provided their Peruvian counterparts with several USGS documents on the Brady prediction. Some of this material subsequently reached the news-

media.Fortunately, press coverage of the Brady prediction soon decreased to occasional articles or to tabloid "specials" due to the intense political campaign to elect a new government, after 12 years of military rule.

As a result of my presentation at Civil Defence, the Peruvian Red Cross decided to make an international appeal requesting aid "as a precaution against disasters". The pertinent document covers a very broad range of items and was obviously designed to meet the disaster that would result from the earthquake(s) predicted by Brady. It included food, medicaments, plastic bags for corpses, hospitals, housing, communications equipment, vehicles and technical assistance, all to be delivered during the period between May 1980 and May 1981. Because of the huge amounts requested, the petition could not possibly be met; even so, the Peruvian Red Cross benefitted from the exercise as it had to evaluate its own capability to cope with a major disaster and to identify needs and assign priorities, this being useful information for international disaster relief agencies.

UNDRO sent a mission to Peru in October , 1980, which came to the conclusion that few specific preparedness measures had actually been taken. Most people in Peru have little alternative but to continue living in their present houses and working in their present workplaces. However, because of the Brady prediction, in a few cases, people who could afford it had their houses inspected and spent money to improve their resistence to earthquakes.

In February, 1980, I was called by the President of Peru to present to him and to his Cabinet a situation report on the Brady prediction. I took the opportunity to request additional funds for IGP to improve its operational capability and to recommend that an official agency be appointed to assume responsibility for all government action with regard to the prediction. A few days later, I was informed that approximately one million dollars were to be allocated to IGP. About one third of this amount was authorized in March, 1980. I was asked to approach foreign governments to explore possible donations of equipment or availability of soft credits for the purchase of equipment before requesting from the Treasury the remaining two thirds. The Government also provided funds for Civil Defence. The President appointed the Executive Secretariat for National Defence, under Executive Secretary-General Ramon Miranda Ampuero, as the agency responsible for handling the Brady prediction. National Defence has to do with military and non-military problems; Civil Defence is a subsystem of National Defence. This arrangement subsisted until the end of the military government in June, 1980.

The new Government revoked legislation imposed by the former regime, changed institutional structures and appointed different people to responsible levels of the public administration, - a common and understandable pattern of behaviour under the circumstances. This attitude may also explain why some of the new Ministers and Congressmen labelled the military as "believers" of the earthquake prediction and denounced Brady as an international terrorist. However, the new Government did support IGP's joint proposal with Carnegie Institution of Washington, to the U.S. Agency for International Development, for a project to study seismicity in Peru, by obligating counterpart funds in the 1981 and 1982 budgets; the project included purchase of seismometers, telemetry and a central data processing facility with an approximate value of $800,000 dollars. Although the proposal did not mention Brady or the prediction, its origin, timing and acceptance were influenced by the Brady prediction.

In May, 1981, the National Council for Science and Technology of Peru (CONCYTEC) asked CERESIS for an opinion on the Brady prediction. Father Cabré, President of the CERESIS Directive Council, in consultation with other Council members and myself, prepared a report summarizing the situation, stressing the fact that Lima, as well as other parts of Peru, should permanently improve the earthquake-reistant charateristics of its buildings, regardless of any given prediction (it must be remembered that, on the average, Lima has suffered four destructive earthquakes each century). Father Cabré as a member of the UNESCO reconnaissance mission to Lima, after the 1966 earthquake, was well aware that many buildings, especially the older structures, do not meet earthquake-resistant standards. The report recommended that Peru improve its capability to detect and analyse seismic events on a national and regional scale, and mentioned the importance of providing the news media with credible and timely official information, CONCYTEC reported to President Belaunde on 22 May 1981.

The national census for 1981 was originally scheduled for 28 June 1981. Because of the prediction, it was postponed until July 12, 1981. It was believed that population data would be distorted because of the significant number of people expected to leave their homes on 28 June, because of the prediction.

2.2 U.S. Government

Reference has been made to the participation and role of U.S. Government agencies involved in the Brady prediction. These were the U.S

Geological Survey, the Bureau of Mines and the Office of Foreign Disaster Assistance of the Agency for International Development (Department of State). the U.S. Geological Survey did not at any time endorse or support Brady's prediction. Nevertheless, it was extremely co-operative in arranging for the two formal meetings held in Golden, Colorado, at the request of the Instituto Geofisico del Peru "to assist Peruvians in their assessment of earthquake hazards in Peru", and for NEPEC's evaluation of Brady's prediction. The USGS also authorized Dr. Jerry Eaton to work with IGP in Peru in connection with a programme for the detection and analysis of earthquake precursors. At the individual level, IGP scientists and executive benefitted from the friendship and understanding of their U.S. colleagues.

Dr. Brady had the support of his employers, the Bureau of Mines, throughout the whole process. He continues to hold a responsible position and is respected by his superiors and fellow workers. As an outsider, I can only venture to state that there probably could have been a better working relationship between Dr. Brady and his scientific colleagues in the USGS had there had been a decision at a sufficiently high level, in the USGS and the Bureau of Mines, to examine the situation jointly, bearing in mind that the problem was not solely seismology or physics but that it had to do with important social and economic questions and international relations.

We received courteous and helpful attention from the Office of Foreign Disaster Assistance (OFDA). It realized the serious implications of the Brady prediction and stressed the importance of being prepared for a disaster, which undoubtedly Peru will suffer sooner or later. However, the Peru prediction was and still is a sensitive issue and I have been told that open discussion concerning its management by agencies and individuals within the U.S. Government remains difficult. This is complicated by the fact that Dr. Brady continues to examine the theory and its implications with respect to possible future events. He is not the only one concerned by the possibility that the coastal segment off central Peru may not have been destressed by the number and severity of seismic events which have recurred since 1946. This region is currently exhibiting an unusual quiescence, which may be an indication that a strong earthquake could occur in the not-too-distant future.

Seismic data from the IGP local network was relayed to Dr. Brady by the U.S. Embassy who handled information relevant to the prediction; on several occasions

we met with the Ambassador to discuss the situation. The U.S. Embassy apparently felt obligated to co-operate with Peruvian authorities because Dr. Brady was a government employee in good standing. The Embassy maintened a low profile except when it publicized the findings of the NEPEC and when, a few days before the first large earthquake was to occur, on 28 June 1981, Ambassador Corr announced that he was bringing his mother and father from the United States to have them with him in Lima on the day of the earthquake. The story, with pictures of their arrival, was on the front pages and on television. The U.S. Embassy arranged for Dr. John Filson, Head of the Office of Earthquakes Studies of the USGS, to come to Lima for a press conference and to remain until after the predicted date, and for experts in disaster preparedness to come to work with Civil Defence.

The U.S. Embassy recommended favourable action on proposals by IGP and CERESIS to U.S. funding agencies. Two projects were approved. First OFDA transferred $500,000 dollars to the U.S. Geological Survey for CERESIS to carry out the initial phase of a four-year earthquake disaster mitigation programme in the Andean region (Project SISRA). The objectives are to produce national and regional catalogues of earthquake hypocentres and intensities, seismotectonic and neotectonic maps and uniform seismic hazard maps for various probability levels and parameters. Second was the IGP-Carnegie Institution proposal to OFDA to upgrade and modernize Peru's earthquake monitoring network, a most appropriate and cost-effective project, given the magnitude of possible disaster which permanently threatens Peru.

3. SOCIAL AND ECONOMIC IMPACT

3.1 Schools

The school system in Peru has both public and private schools. In 1981, 3,238,000 students aged 6-12 attended primary grades, 1,257,000 aged 13-18 attended secondary grades, and 250,000 adults were enrolled in primary or secondary schools. Thus, the school population in 1981 was 4,745,000, approximately one quarter of the total population of Peru. There are 90,000 teachers in primary, and 50,000 in secondary, in some 25,000 school units.

The effect of the Brady prediction in schools is therefore significant as a reference for the behaviour of the population. My impressions are derived from interviews with teachers and students in several Lima schools of different categories. This sample appears to be representative of a general pattern.

Before 1980 there was no significant effort in schools to increase the awareness of the seismic environment, with two exceptions: (1) at Reina de Los Angeles, which had suffered partial collapse of its modern building due to the 1974 Lima earthquake possibly because of faulty construction and higher-than-expected soil response, and (2) at San Silvestre, also a good private school for girls (1,200 students) which for years has had orderly drills at least once each semester and maintains a well organized system for evacuation, disconnecting power and gas mains , quick access to fire extinguishers, first aid stations and signs; students and teachers are permanently trained and assigned specific tasks. At both of these schools the Brady prediction motivated further improvements in design and construction of their buildings, removal of dangerous objects that could fall on people, widening of stairs and doorways, rounding off all sharp edges, more frequent unannounced emergency drills, involvement of parent-teacher associations through teaching aids (films, text-books, and talks with students, parents and teachers), thus gaining a better understanding of earthquake hazard and risk.

Because of the prediction, Civil Defence and the Ministry of Education staff inspected school buildings, designed and posted evacuation routes with cardboard or painted signs and lectured on the subject. The people we interviewed report that (1) there was general indifference to the prediction, speakers and teachers designated to discuss the problem only partially complied and attendance at such talks was minimal; typically a seminar was attended by 20 teachers out of a possible 300; (2) the competence of the speakers was, in general, poor; at ESAN, a post-graduate institution for executives in business administration, the lecturer (a lawyer commissioned by Civil Defence) began his talk disqualifying Brady because, "as far as he knew, Brady had never personally inspected the subduction zone in a submarine"; (3) the recommendations to reduce the vulnerability of the structures were impossible to carry out because of high cost and bureaucratic impediments; (4) printed instructions for preventive measures were distributed via the Ministry of Education; a first version, which unfortunately was widely circulated and given publicity by the official television Channel 7, recommended that the refrigerator be kept well stocked; that a two to three weeks' supply of canned food be purchased; that fresh water be kept in large containers and changed twice a week adding chlorine pills; that at least two large flashlights be handy with replacement cells; that a well-equipped first aid-kit, sleeping bags and a transistor radio, be readily accessible and in a safe place. For probably more than 85% of Lima's population, such recommendations, probably valid for the

United States, the USSR or Japan, were meaningless. In Peru, people still buy water daily, in cans, and thousands go to the market to purchase a subsistence amount of food each day; in view of their incapacity to find the money to pay for preparedness measures of the kind recommended, it seems that the majority of the population came to the conclusion that the Brady prediction was a problem for the rich.

An ambitious exercise was carried out by Civil Defence on 29 November 1980. At schools throughout Peru, bells and alarms sounded during 30 seconds to simulate the occurrence of a severe earthquake. Several days of practice preceded this exercise, including rapid and orderly evacuation, tending to the wounded and fighting fires. To be effective, this type of action must be a sustained programme at each school, because students change class-rooms every year, and as they grow their own perspective changes.

A few positive effects have been achieved. Occasional evacuation drills are carried out and in a disciplined manner; some new schools are to be one-story buildings with direct exit to open areas; in some places, students are instructed on what to do during and immediately after an earthquake. However, in general, class-rooms and assembly-halls are again filled well beyond capacity; signs to show evacuation routes have either been painted over or removed; no major programme has been implemented to reduce the vulnerability of school buildings; there is no sustained effort on the part of the Civil Defence, directly or through the Ministry of Education, to improve the situation, according to the teachers interviewed. It would seem that without Brady, Peru's earthquake problem has disappeared.

We examined the correlation of student absenteeism with rumours of impending earthquakes, earthquake headlines and the dates of the predicted large earthquakes. One conclusion is that there is a correlation between absenteeism and the economic level of the families of the students. In the public schools and the poorer private schools there was no apparent effect of the prediction on school attendance; in the rich private schools there was a noticeable effect; for example, 1,5% of the families took their children to some other country; others left Lima for cities in the interior. Rumours had an effect at all schools; it is almost impossible to know how rumours start, but typically some teachers would receive a call stating that the Geophysical Institute or the Ministry of Education had announced that the earthquake would take place two or three hours later; the usual action was to have the students go home. This happened rather frequently but the rumours did not affect more than a few schools at a time.

Perhaps as a result of the Brady prediction, Unesco's programme for Environmental Education asked CERESIS, in 1980, to carry out a pilot project in the area of seismology. This was implemented with the co-operation of the Ministry of Education. Visual aids, cartoons, slides and texts have been prepared and will be included in the regular school programme after a period of evaluation.

3.2 Insurance

Rates for earthquake insurance did not change in response to the Brady prediction. Some 85% of large and medium-large Lima industry is covered normally by such insurance, whereas the number of policies for residences has been rather low. In 1981 there was an increase of about 35% in the number of policies for residences. Many home-owners and small businesses who did not have the infrastructure to analyze their risk management problem in the light of the prediction's real implications apparently decided not to assume such an "imminent" risk. This seems a reasonnable decision specially because of the relatively low cost of buying insurance for a short period at a rate based on losses with long recurrence intervals. There is evidence that in 1982 some of these policies for earthquake cover of private homes will not be renewed.

Some of the large and medium-large industries did modify their normal practice by adding coverage of "loss of profit" due to earthquake damage, so as to be covered during the period that their plants were non-operative. There is also some evidence that this type of added coverage was not generally renewed in 1982. Most large industries apparently analyzed their risk management practice with respect to earthquakes and Brady's prediction of a terrible catastrophe and decided that there was insufficient justification to change their traditional practice.

In 1980, the total amount of earthquake insurance in Peru was of the order of 4,900 million dollars as compared to 6,400 million in 1981. The increase of 1,500 million dollars may not be too significant, considering normal growth and inflation, but certainly the increase in number of policies, specially for individual homes, does not seem to be a direct effect of the prediction.

3.3 Tourism

Statistics on the number of foreigners that enter Peru may not be a reliable guide to the effect of the prediction on tourism. 293,447 entered in 1978, 338,468 in 1979, 372,790 in 1980, and 334,819 in 1981. The numbers typically increase by 10% to 15% from one year to the next, as noted from the figures for 1978 to 1980 and in preceding years. One would expect that in 1981, some 420,000 people, mostly tourists, should have come to Peru; the actual number was 25% below that estimate. There may be other reasons for this decrease besides the Brady prediction, but this needs to be investigated. Monthly figures for 1981 do point to the decrease in the high-season months of June and July, and tourist agencies state that the number of tourists was 35% less than expected. The loss of revenue to Peru, on the basis of such information, can be estimated to have been about one hundred million dollars. Two lawyers initiated formal legal action to sue Dr. Brady, but the case was rejected by the District Attorney and by the Court of Appeals on the grounds that there was insufficient evidence. These same lawyers also asked the Congress on Problems of Latin American Nations, sponsored by the Universities of Yale, Harvard and Georgetown, to take notice of the situation and condemn Brady.

The total number of nationals leaving Peru in 1981, would seem to indicate that fewer people did so than could have been expected from the normal year to year increase, except for the fact that in July 1981, more Peruvians left Peru than during any one month in the previous four years. Tourist agencies and airlines stated that all flights leaving Peru in May, June and July 1981, were fully booked. There is some evidence that more that usual of the foreign employees of Embassies, international agencies and transnational companies requested vacations during this three-month period.

3.4 Real Estate

The effect of the prediction on value of property was noticeable in La Punta, a small upper-middle class suburb, situated on a peninsula adjacent to the port of Callao with an average elevation of only one metre above sea-level.

The Naval Academy of the Hydrographic Office is located in La Punta. The Hydrographic Office is responsible for the tide-gauges along the Peruvian coast

and participates in the Tsunami Warning System for the Pacific Ocean. Early in 1981 this Office delivered to all the homes and other buildings in La Punta a brochure with technical information on tsunamis, as a normal service to the community. Although the brochure did not refer to the prediction, people associated the timing of its distribution with concurrent prediction publicity via the news media, and this heightened awareness of potential danger was the reason for dozens of home-owners to try to sell their La Punta homes. Those that were able to find buyers did so at a significant loss. In other areas of greater Lima there is no evidence of a similar large-scale effect, but more research on the subject is required.

3.5 News media

Press coverage of the Brady prediction did not start until the last quarter of 1979, three years from the date Brady published his paper in Pure and Applied Geophysics.

A Harvard professor attending the VIth Pan-American Congress of Soil Mechanics and Foundation Engineers, which took place in Lima on 2-7 December 1979, was quoted as being of the opinion that the Brady prediction for 1980 had a 20% probability of being correct; another participant, a Peruvian engineer with strong political views, thought that the "Beard" (meaning Brady) prediction was a plot of the military government to remain in power; a Dr. Sowers was quoted as being the real author of the prediction and as stating that the tsunami generated by the earthquake would endanger 2,000 million people living in the coasts of the Pacific Ocean; a geologist supposed to be an authority, said that the cause of earthquakes was the energy released by the river sediments dropping 5,868 m. into the deep trench off the coast, and that the whole coastal highway would drop into the sea. The two most widely read weekly magazines, Gente and Caretas, published generally accurate information and avoided statements that would cause undue alarm.

During the following 18 months the Brady prediction was well publicized in the twelve Lima daily papers, the three principal weekly magazines and radio, but not much on TV. The total space dedicated by newspapers and magazines is equivalent to approximately a 6cm wide column, more than 600 metres long, or nearly 400,000 square centimetres. Not more than about 25% was useful, relevant, reliable, and timely information. The rest, mostly in tabloids, even went so far as to invent interviews with Brady, quote "authorities" such as the winner of a

Miss Bikini contest, head-lined that Brady confirmed Saint Rose's sixteenth century prediction that the sea would cover the Plaza de Amas of Lima (in fact there is no historical evidence that St. Rose of Lima ever made such a prediction, but it is popular belief). This type of press, and even the more conservative newspapers, discovered a great number of Peruvian experts on earthquake prediction, who were quoted at length on why Brady's theory was correct or incorrect, although it is certain that none of them had ever read any of Brady's papers. Between March and October 1980, the prediction was almost forgotten; this was because of the election campaign and change of government after 12 years of military rule.

One particular tabloid (P.M.) printed on its front page during 35 consecutive days sensational news about the earthquake; its central page was a blank with only a small caption which stated: "Mr. President: this space is reserved for your message to our people concerning the earthquake". Some papers, and the weekly magazines, published results of polls, according to which some 75% of the people were simply not interested or worried about the forthcoming earthquake.

Rumours and their effects received considerable press attention. There were four occasions when rumours caused panic. These occurred on 14 January 1980, 18 March 1980, 16 March 1981 and 25 June 1981, and in all cases they related to tsunamis that would destroy the city of Callao, Lima's port. People evacuated homes and headed for Lima causing incredible traffic jams. It was necessary for Civil Defence, police and government officials to intervene to bring things back to normal. It is curious that this source of fear cannot be eradicated in as much as a tsunami is the kind of catastrophe which can be foretold. The Pacific Warning System can estimate arrival times with 10 or more hours' notice for tsunamis generated in distant parts of the Pacific, whilst tsunamis generated near the coast of Peru can be expected within some tens of minutes after a strong earthquake occurs. This is an area where public education, through the news media, on short-term preparedness measures can be very effective.

The seminar on earthquake prediction held in San Juan, Argentina, in October 1980, motivated considerable press coverage in San Juan, some of which including specially Brady's prediction for Peru was reproduced in the Buenos Aires papers. The international news service circulated the story all over the world and the same story was recycled back and forth between Peru and foreign news media.

There were two peak periods in the news coverage of this prediction, one from November 1980 through February 1981, and the other from April to July 1981, during which almost every newspaper had two or three times a week some reference to the prediction itself or to the general earthquake hazard. It is undeniable that a prediction is newsworthy and such news increase sales. El "Diaro de Marka" (a serious paper) had a one-week series of well-written articles on the earthquake prediction and it sold about 50% more copies than on the average. Daily sales of Lima newspapers were of the order of 600,000 to 650,000 in the period 1975-80, when the press was under government control. Since 1980 with a free press, sales have increased to about 900,000 daily. The change from a controlled to a free press, in mid-1980, distorts the effect of the prediction on circulation figures. In addition, statistics on day-to-day circulation of many newspapers are not readily available.

Our estimate of radio time dedicated to the prediction during the same 18 month period is about one thousand hours. One particular station mentioned the prediction in at least 50% of its daily morning broadcasts during the first half of 1981.

One of the important television companies produced a documentary film on the prediction, including interviews with Brady and Spence. It illustrated quite well the geophysical and geological characteristics of Peru and its seismic environment. However, for some reason, the decision was made to cancel its public release which had been scheduled for a date before that of the predicted earthquake, and this useful material has disappeared into the archives.

4. CONCLUDING REMARKS

4.1 A mechanism should be adopted by the scientific community to bring about automatic peer review of any bona-fide scientific paper that forecasts or predicts a specific earthquake that will have destructive effects anywhere, in in particular in countries that are not able to evaluate such a prediction by themselves. In the case of Dr. Brady, his paper was accepted for publication in an accredited international scientific journal, on the basis of its scientific merits. The reference to a possible catastrophic earthquake in central Peru was somewhat buried in the text, and perhaps this explains why neither the U.S. scientific community, as such, nor that of other advanced countries took the time or had the

interest to analyze this prediction. The general reaction might have been that Brady's forecast was not to be taken at face value. It was only because of the persistence and interest of Peruvians that the USGS and NEPEC became involved.

A mechanism to achieve active co-operation whereby immediate evaluation and pertinent recommendations are formulated, and re-evaluated as the prediction evolves, could be the responsibility of IASPEI or ICSU, as a first step, and subsequently of inter-governmental agencies such as Unesco and UNDRO. Dr. Spence's experience with the Brady prediction should not be ignored. We are thankful for his participation and are glad to know his scientific stature did not suffer from his association with Brady but to the contrary. Spence believes that as scientists better understand the physics of the earthquake process and are tempted to predict earthquake occurrences, they should move slowly and rationally, with plenty of discussion, hypothesis-testing, hard thinking prior to publication, and to couch predictions in terms of well-defined conditional probabilities which can be up-dated. A predicting scientist should maintain a perspective that can change pro por con with the acquisition of new data and, if so, should expect help and not reprisals from the seismological community. Spence believes that the precise prediction of an earthquake is an extremely difficult scientific problem; however, the very occurrence of great earthquakes makes attempts to predict these potentially catastrophic events an expectation that the seismological community is forced to live with; the problem must be approached with the view that the social benefits greatly outweight the social detriments. Responsible agencies should encourage earthquake prediction research and document prediction scenarios and case histories to really understand the complex social, political and economic ramifications of what must remain a purely scientific endeavour.

It must be realized that as seismology progresses the effect of predictions such as Brady's will become worse before it becomes better. In other words, one must assume that future Bradys may be more knowledgeable, with a better data base, new insight as to the genesis of earthquake and so on, - hence the prediction should be relatively more reliable and the probability of success will be greater than Brady's, certainly the chances for failure will still be more than those for success, for some time to come. Therefore, the problem of handling a prediction will become more and more difficult as the science progresses and predictions cannot be ignored, making it more difficult for governments to take decisions and guide public reaction.

4.2 Some of the benefits to Peru from the Brady prediction are that:

a) IGP is now better equipped to cope with the problem of detection, location and real-time analysis of earthquake events.

b) The Ministry of Education is giving support to the project of Environmental Education in Seismology, begun under auspices of Unesco and CERESIS, to educate the population to better cope with earthquake risk mitigation.

c) The Brady prediction has called our attention to a problem that is not unique to Peru: Government institutions do not readily co-operate or help each other. They have an aversion to free exchange of data and know-how, because of the competitive attitude which some times places institutional prestige above national objectives; institutions compete for limited financial resources; each aspires to be hegemonic in its field even when its competence may be minimal. At a personal level, institution heads and staff members do maintain a working relationship, but institutional behaviour needs to be greatly improved.

d) The Brady experience has made the government receptive to the proposition that an international site for research oriented to the prediction of earthquakes be established in Southern Peru. The area of Southern Peru and Northern Chile was proposed for such a site by the Group of Experts, invited by Unesco, which met in London, Ontario, Canada during the IASPEI General Assembly last year.

4.3 This paper does not attempt to be more than a partial and brief report of the Peru prediction from a personal point of view. Invited by CERESIS, a group of experts from the United States, New Zealand and Peru is considering the suggestion that a formal Working Group be established to produce a well-documented, comprehensive, and unbiased analysis of its development and consequences.

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REFERENCES

Brady, B.T., 1976
Theory of Earthquakes, IV, General Implications for Earthquake Prediction, Pure and Applied Geophysics, 114, 1031-1082.

Spence, W., 1978
Conference Report: Toward Earthquake Prediction on the Global Scale. EOS, Vol. 59, No. 1.

Extensive reference was also made to files on the Brady prediction at the Instituto Geofisico del Peru (IGP) and at the Regional Centre for Seismology for South America (CERESIS), and to the file of news-media articles at CERESIS.

DISCUSSION

In reply to a question, Ing. Giesecke said the report of the US National Earthquake Prediction Evaluation Council (NEPEC) was not widely publicized in Peru because the media were interested more in reporting affirmative information on the prediction than in discrediting it.

On whether Brady's theory remained credible or not, Ing. Giesecke observed that it does work on rock bursts in mines but it may be questionable if extrapolated to a large area.

Dr. Tomblin pointed out that some of the agencies or individuals called upon to evaluate the prediction had also been asked to recommend preparedness measures for a major earthquake. The extent to which they challenged the arguments of Brady may have been tempered by the desire to use Brady's scenario as a means of promoting better monitoring and preparedness planning.

Prof. Roberts suggested that the Brady prediction was based on a hypothesis which was so elaborate that its validity has never been examined in full detail.

Prof. Nigg stated that it would be difficult to establish a code of ethics with regard to the media. She questioned whether the international agencies could help to make the press more aware of the need to maintain a realistic perception of earthquake risk.

Prof. Lomnitz proposed that in any publication on the subject of earthquake prediction by a foreign scientist, at least one co-author should be sought from the country to which the prediction referred.