EXECUTIVE SUMMARY

The panel reviewed 16 evidential documents (comprising over 200 pages and covering all aspects of UK-IODP activities). We also interviewed 6 members of the IODP community (including the Director of BGS, the leader of UKIODP, Liaisons from Industry and a senior and a post-doctoral researcher). During a two-day in-depth evaluation it came to the following conclusions relative to its terms of reference:

Terms of Reference

The two main objectives of the NERC Ocean Drilling Review are to:

1. Advise on the past performance and value for money of the UK's involvement in the Integrated Ocean Drilling Programme – in terms of scientific excellence and impact, science community and national economic benefits, and the delivery of NERC's current (and previous) science strategy;
2. Advise on the potential future benefits and value for money from the UK's continued involvement in ocean drilling and its potential to deliver NERC strategic and science priorities.

In addition, the Review will:

3. Advise on the relative priority for UK science of the three IODP platforms in the future ocean drilling programme.

Term of Reference 1

Having reviewed the evidence, the panel considers that the programme has delivered excellent science with high impact that is strongly aligned with many of the science themes and the People and Partnerships themes of the NERC Strategy. The UK-IODP community is well-connected nationally and internationally. It provides strong UK leadership of the international programme. UK-IODP facilitates accelerated career progression for early career researchers. The panel has seen that IODP has real economic benefits to UK industry.

The main findings are:

- Output of the programme is excellent as judged by quality and number of related publications and their influence (citations) beyond the IODP community.
- Major advances in understanding would not have happened without IODP such as knowledge of deep crustal structure, deep biosphere, palaeoclimate including the Palaeocene-Eocene Thermal Maximum (PETM), evolution of the Arctic, and subduction tectonics.
- The NERC investment has been £47M over 10 years (NERC national capability subscription plus the UK-IODP research programme) in an overall IODP programme costing in excess of $2Bn. For this <3% contribution, the UK makes ~15% of sample requests, is involved in ~15% of the publication outputs, ~10% of drilling proposals and has provided co-chiefs for around 10% of the Expeditions. Thus, UK leadership and influence internationally is disproportionately high in terms of investment made.
- The programme is especially well aligned with the Earth Systems Science theme and also contributes to the Climate System and Biodiversity strategic NERC science themes as well as the People and Partnerships themes. The panel also heard evidence of the development of technology which addresses, but is funded independently of, the Technologies theme.
- The panel has seen clear evidence that UK-IODP develops an excellent group of trained post-graduate and post-doctoral researchers that is highly valued by academia and industry. The

exceptional networks developed by IODP are very important to the career development of this group.

- It is clear from the feedback from industry (including panel interviews) that they make significant use of the data generated from IODP, particularly published literature and also archived samples.
- The programme's Knowledge Exchange achievements were not as highly rated by the academic community for reasons that the panel has not been able to identify.
- The panel was concerned about the recent reduced level of activity of the Industrial Liaison Panel (ILP), but applauded its expansion from the UK into the European Consortium for Ocean Research Drilling (ECORD).

Term of Reference 2

Based on the evidence presented, the panel considers that successive ocean drilling programmes have continued to be highly effective and relevant not withstanding numerous changes of NERC strategy, and the panel expects that effectiveness to continue. The panel strongly advises that future NERC investment in the ocean drilling programme post-2013 should be such as to enable the UK to continue to achieve NERC's strategic goals from a sustained leadership position. The NERC subscription to the new programme will be determined by international negotiation over which the panel has no control, but the panel recognises that there will be an investment threshold below which the UK will lose its disproportionate benefits. This threshold may be similar to or slightly less than the current subscription of $5.6M per annum. It is recommended that an associated research programme should be maintained in order to maximise the benefits from the subscription, and the panel judged that this can be achieved with a similar level of funding to the current phase of the UK-IODP research programme (i.e. £7m over 5-years).

- On the basis of past achievements of the programme, the panel expects that novel scientific discoveries will emerge from the activities of the UK within the future programme.
- There is strong UK representation in up-coming drilling proposals. This planned IODP activity in the next five to seven years should lead to exciting scientific advances by UK scientists in areas including climate change (higher spatial and temporal resolution data); understanding deep ocean crustal structure; the biogeochemical functioning and biodiversity of the deep biosphere.
- The panel anticipates that IODP will continue to deliver effectively against NERC Strategy and has the potential to contribute substantially more towards the Natural Hazards and Sustainable Use of Natural Resources Themes than in the past.
- The planned activities of IODP should particularly contribute to NERC's aspiration to expand its research in the Arctic. The panel has heard evidence of industry's enthusiasm for drilling in the Arctic.
- With the use of sea floor rock drills as Mission Specific Platforms (MSPs), there is an opportunity for British Geological Survey to play a leading role in addition to its current function as ECORD Science Operator.
- The existing associated research programme (including site survey investigations) should continue in order to capture benefits from investment in the subscription. The panel notes the potential for accessing pre-existing, mostly industry, geophysical data as a very cost-effective mechanism for 'virtual' site surveys, where the UK is a world leader. The evidence is that the present level of research programme investment is leading to high quality outputs.
- Evidence acquired from industry demonstrates that they want to engage with IODP and would do this best initially around a focused research programme in the Arctic. On that basis the panel is reassured that in the future programme's funding model, interaction and co-funding with industry (especially in Europe via the ECORD Industry Liaison Panel) may be easier.
- Industry also expressed enthusiasm for the potential use of CASE studentships, because they were concerned about the supply of a trained workforce.
- The panel is confident that there are emerging leaders of the UK-IODP who will maintain the UK's international profile.

- The panel would advise continued use of UK-IODP as a very effective vehicle for graduate training.
- The UK-IODP community could do more to engage more widely in Knowledge Exchange (KE) activities but they need help and facilitation from the dedicated KE group within NERC.

Term of Reference 3

The panel recognises that all three present platform types (riser drilling - Chikyu, non-riser drilling - JR, and Mission Specific Platforms - MSPs) provide complementary and unique sea floor sampling opportunities. The panel considered the best way to prioritise the NERC investment across the three platforms is: maintain a balanced portfolio between MSP and JR operations and encourage IODP to realise the Chikyu's potential on the global stage in the next five years.

- The JR and MSPs support delivery of different types of science: MSPs provide access to samples in areas of the sea floor (shallow water, ice-covered areas, surficial hard rock) not accessible by the JR. The JR provides the complementary longer and deeper water cores that have been the mainstay of the programme since its inception. The panel found convincing scientific evidence that both capacities are needed.
- The panel recognizes that Europe, and particularly the UK (BGS) are international leaders in sea bed rock drill operations which will provide important MSP capabilities in the future. This is of particular relevance to the NERC Strategic Theme in Sustainable Use of Natural Resources.
- Evidence shows that the Chikyu is not as widely used by UK scientists at present as other platforms and therefore is not a top priority for UK support. Nevertheless it has the potential in the medium-term to offer real advances especially in the fields of geohazards and the study of deep crustal processes. In order to realise this potential benefit to the UK, three conditions would have to be met: (i) timely delivery of Chikyu's current scientific programme; (ii) expansion to global activity; (iii) strengthening of the engagement of the UK community in Chikyu activities.
- The panel emphasises that NERC should endeavour to ensure that at least the current level of MSP activity is always possible even if this precludes a 12-month programme for the JR. This is driven not only by the scientific benefits of MSP drilling, for example Arctic drilling (NERC's priority for polar science and Arctic exploration), but also by the enthusiasm shown by mainstream industry for partnerships, and strong UK technical capability in this area.

Conclusion

The panel was particularly struck by a comment from an industrial correspondent who wrote "*To even think that the UK would consider stepping out of support for the IODP is, quite frankly, bizarre*". This statement was endorsed by the industrial interviewees. Based on UK-IODP scientific productivity and its relevance to delivering NERC Strategy, the panel agrees. The panel recommends that NERC maintains the subscription and Research Programme at levels that secure the disproportionate benefits to the UK that have been delivered thus far. The panel cannot prejudge the outcome of the negotiations but based on indications from our international partners there is the prospect that these benefits could be achieved at current levels of expenditure, or even slightly less.

NATURAL ENVIRONMENT RESEARCH COUNCIL

UKIODP Review Contents

1. INTRODUCTION

1.1 Background

The NERC Council (following advice from the National Capability Advisory Group) requested that a small panel of independent experts should carry out a review of NERC's support for ocean research drilling activities. The outputs of the review will contribute to the decision making process regarding the future involvement and membership of the UK in the international Integrated Ocean Drilling Program (IODP).

This document is the final report of the NERC Ocean Drilling Review Panel and reports against each review Term of Reference in turn, aligning detail with the overarching statements made in the Executive Summary.

NERC has a long history of supporting ocean drilling – currently via the IODP (2003-2013) and its forerunners, the Ocean Drilling Programme (1983-2003, 111 expeditions) and the Deep Sea Drilling Programme (1968-1983, 96 expeditions). NERC currently commits $5.6M per year to its membership subscription to IODP and this provides UK scientists with access to the three IODP platforms (*RV JOIDES Resolution*, *RV CHIKYU* and Mission Specific Platforms) and supports a number of integrative activities (including core repositories). In addition, the science funding for UK ocean drilling related research comes from NERC's UK-IODP research programme (amounting to £7M over the five years from 2008-2013) and Responsive Mode, and from non-NERC sources (for example, the European Commission Framework Programmes, industry, and UK Universities).

UK-IODP was launched in 2003 and manages the UK's membership of IODP through the European Consortium for Ocean Research Drilling (ECORD). Overall NERC will have committed the equivalent of $45.6m to membership (over ten years, until September 2013) as part of UK national capability, and invested £10.5M in the UK-IODP research programme (over 10 years).

1.2 Review objectives

Terms of Reference
The two main objectives of the NERC Ocean Drilling Review are to:

4. Advise on the past performance and value for money of the UK's involvement in the Integrated Ocean Drilling Programme – in terms of scientific excellence and impact, science community and national economic benefits, and the delivery of NERC's current (and previous) science strategy;
5. Advise on the potential future benefits and value for money from the UK's continued involvement in ocean drilling and its potential to deliver NERC strategic and science priorities.

In addition, the Review will:

6. Advise on the relative priority for UK science of the three IODP platforms in the future ocean drilling programme.

An independent review panel was convened to provide NERC with an assessment of the benefits of ocean drilling to UK science. This review examined all of the available evidence to assess the benefits of IODP and advise NERC of ocean drilling's potential to deliver strategic science in the future.

The call for evidence from the scientific and user community closed on August 10th 2010. **89 responses** were received (52 from the UKIODP community, 24 from the wider scientific community and 13 from the 'user' community).

1.3 Timetable

The methodology for the review is based on that used for previous evaluations of directed programmes, formulated in consultation with the NERC Evaluation Team Leader. The timetable for the review is detailed below.

Call for evidence published	May 2010
Call for evidence open	May – August 2010
Collation of evidence	August - November 2010
Review group meets	December 2010
Final Report	February 2011

1.4 Panel Meeting

The panel membership was:

Professor Sir William Wakeham [**Chairman**]
Prof. Colin Devey (Deputy Director, IFM-GEOMAR)
Prof Tony Fallick (SUERC)
Prof Colm O'Cofaigh (Durham)
Prof John Shepherd (NOC)
Prof Tim Jickells (NERC Theme Leader, Earth Systems Science)

The review panel met on 6-7th December 2010. The panel reviewed 16 evidential documents prepared by NERC officers (see **Annex I** for list and description of papers) and submissions from the science community. The evidential documents comprised over 200 pages and covered all aspects of UK-IODP activities. In addition, responses provided to an evidence-gathering questionnaire by 89 members of the UK-IODP, wider scientific and user communities were examined. The panel also interviewed six members of the IODP community (including the Executive Director of the British Geological Survey (BGS) and the leaders from UK-IODP and the Industry Liaison Panel, a senior researcher and a post-doctoral researcher – see **Annex II** for list of interviewees). In addition, a tailored statement of input was submitted from the Geological Society of London in support of the programme.

The panel wishes to emphasise that this review, in comparison to the more light-touch 2007 UK-IODP review, considered a vastly more detailed evidence-base and was therefore considerably more quantitative and comprehensive.

2. TERM OF REFERENCE ONE

> ***Term of Reference 1***
> Advise on the past performance and value for money of the UK's involvement in the Integrated Ocean Drilling Programme – in terms of scientific excellence and impact, science community and national economic benefits, and the delivery of NERC's current (and previous) science strategy;

Having reviewed the evidence, the panel considers that the programme has delivered excellent science with high impact that is strongly aligned with many of the science themes and the People and Partnerships themes of the NERC Strategy. The UK-IODP community is well-connected nationally and internationally. It provides strong UK leadership of the international programme. UK-IODP facilitates accelerated career progression for early career researchers. The panel has seen that IODP has real economic benefits to UK industry.

The output of the programme is excellent as judged by quality and number of related publications and their influence (judged by means of citations) beyond the IODP community.

There were many comments in the questionnaire responses about the high impact factor publications that arose directly from IODP involvement. This is also borne out by the publication statistics in Appendix F of the panel papers (see **Annex I**), which show that between 2003 and 2010, 56 papers directly attributable to UK involvement were published in Nature and Science, a further 6 in Nature Geoscience and almost 50 more in the next tier down of high impact journals such as Geology and Geophysical Research Letters. UK researchers were involved in a total of 1,807 papers related to UK-IODP samples and research (including NERC funded publications, results from ISI Web of Science search, publications listed on the UK-IODP Interim Report and publications held on the IODP Publications Database). A total of 269 (15 in *Science*/*Nature*) known publications resulted directly from NERC funding (research programme, 2003-2010) and Responsive Mode funding (2005-2010) relating to research using IODP samples. The panel also noted that UK-IODP produces and chooses to report a significantly smaller fraction of 'grey literature' (non-peer-reviewed output) than other NERC programmes (e.g. RAPID, QUEST) about which it had information.

The high-calibre research performed within UK-IODP is also confirmed by the fact that 16 out of the 19 RAE-top-grade university geoscience departments as well as NERC institutions and collaborative centres make significant use of IODP output. The output from IODP is also very important for other NERC research programmes, such as the QUEST research programme.

The panel recognised that even after allowing for the limitations imposed by bibliographic evidence alone, UK-IODP is producing excellent scientific outputs.

Major advances in understanding would not have happened without IODP such as knowledge of deep crustal structure, deep biosphere, palaeoclimate including the Palaeocene-Eocene Thermal Maximum (PETM), evolution of the Arctic, and subduction tectonics.

The influence of publications reaches far beyond IODP community science itself to reach a very wide scientific audience (e.g. the Nature papers[1,2], which confirmed that the Arctic was once a freshwater lake). The panel is convinced that UK scientists are well-integrated into all the high-profile scientific discoveries made and boundaries broken by IODP. Some examples include:

- The Arctic drilling[3];
- Key work in understanding climate change in the present and past[4,5];
- Crustal penetration drilling allowing direct evidence of the composition and structure of the igneous oceanic crust[6];
- The expansion of the physical evidence for, and reconstruction of, past sea level and ocean chemistry changes.[7,8,9]

The NERC investment has been £47m over 10 years (national capability subscription plus the UK-IODP research programme funding) in an overall IODP programme costing in excess of $2Bn. For this <3% contribution, the UK makes 12% of sample requests, is involved in 16% of the publication outputs, a comparable fraction of drilling proposals and has provided co-chiefs for around 10% of the Expeditions. Thus, UK leadership and influence internationally is disproportionately high in terms of investment made.

In the current programme (2003-2013) there are three main partners: US, Japan and ECORD (the European consortium). Overall operating costs have been around $2Bn. In addition, the US and Japan have contributed **capital** to provide IODP infrastructure (vessels – riser drilling, Chikyu; non-riser drilling, JOIDES Resolution – and core-stores in the US and Japan) at the billion dollar level, whilst Europe and the UK have not directly invested in major infrastructure. The Europeans have an agreement by which the UK, Germany and France all contribute equally to recurrent costs (at the level of one subscription unit each). For the UK, this has amounted to a total commitment of around £47m (£36.5M in national capability[10]; £10.5M in UK-IODP research programme funding) over this 10 year period. Together with minor contributions from other countries, this allows the European subscription to reach a threshold where ECORD is considered a full partner in IODP. This enables Europe and especially UK to play a leading role in the programme, with the UK providing ~3% of the total IODP programme operations budget (i.e. excluding the US and Japanese **capital** contributions). For this 3% contribution, the UK makes about 12% of sample requests, is involved in 16% of the peer-reviewed

[1] Moran, K. et al., The Cenozoic palaeoenvironment of the Arctic Ocean. *Nature* **441** (7093), 601-605 (2006).
[2] Jakobsson, M. et al., The early Miocene onset of a ventilated circulation regime in the Arctic Ocean. *Nature* **447** (7147), 986-990 (2007).
[3] http://www.eso.ecord.org/expeditions/302/302.php
[4] Rickaby, R.E.M. and P. Halloran, 2005. Cool La Nina during the warmth of the Pliocene?*, SCIENCE*. 307, 5717, p. 1948--1952.Beckmann, B., et al., 2005.
[5] Orbital forcing of Cretaceous river discharge in tropical Africa and ocean response*, NATURE*. 437, 7056, p. 241--244.
[6] Wilson, D. et al., Drilling to gabbro in intact ocean crust. *Science* **312** (5776), 1016-1020 (2006).
[7] Thomas, A.L., G. M. Henderson, P. Deschamps, Y. Yokoyama, A. J. Mason, E. Bard, B. Hamelin, N. Durand, and G. Camoin, 2009. Penultimate deglacial sea level timing from U/Th dating of Tahitian corals*, Science*. 324,1186-1189.
[8] Merico, A., T. Tyrrell, and P.A. Wilson, 2008. Eocene/oligocene ocean de-acidification linked to Antarctic glaciation by sea-level fall*, Nature*. 452, 7190, p. 979--U6.
[9] Coggon, R. M. et al., Reconstructing Past Seawater Mg/Ca and Sr/Ca from Mid-Ocean Ridge Flank Calcium Carbonate Veins. *Science* **327** (5969), 1114-1117 (2010).
[10] Current UK subscription is $5.6m per annum

publication output (2004-2010), makes a comparable fraction of drilling proposals and will have had co-chiefs on 10%[11] of the expeditions by the end of the current programme. In addition, this contribution provides for open access/participation in all IODP activities and resources for all UK scientists, which for a community of ~450 UK active researchers (including PhD students) represents a cost to NERC of around £10k pa per researcher (i.e. UK annual contribution divided by number of researchers).

In terms of the UK's use of IODP resources (samples, data), of the wider academic and user community, 21 out of 36 respondents to the evidence-gathering survey have used IODP resources. As a percentage of total requests to (i) the US's Gulf Coast Core Repository, the UK is second highest at 12% (to the USA at 47%); (ii) Europe's Bremen Core Repository in Germany, the UK is third highest at 16% (to Germany at 19% and the USA at 33%); and, (iii) the Japan's Kochi Core Centre, the UK is the second highest after the USA.

There is good evidence for influence across the international programme with a leverage factor of 3 to 6 in terms of UK participation on expeditions. International leadership from the UK is disproportionately good in terms of investment with UK representation on all of the IODP Science Advisory Panels, the IODP Triennium Review Committee, the INVEST[12] Steering Committee, 3 out of the 15 members of the peer-elected New Science Plan writing group (including Chairman of the group) and 8% of all expedition participants. However, it was not clear to the panel whether the UK takes a similarly disproportionate lead within the European consortium itself, as opposed to participating at the 'juste retour' level, as no definitive evidence was presented to the review. Neither did the evidence give a picture of how other European nations' leadership in IODP compares to that of the UK, although it was noted that the first ESSAC[13] Chair was held in the UK for the first two-years of IODP and that much of the ESSAC best practice was started here. In addition, the ECORD European Petrophysics Consortium joins up the three main countries in ECORD (UK – University of Leicester; France – University of Montpellier; Germany – University of Aachen). However, the evidence may become clearer following the independent review of ECORD in early 2011, from which a Review Report should be available towards the end of 2011.

In general the UK is seen as a strong contributor to the international programme with an excellent profile. Many of the UK participants are leaders in their fields (e.g. palaeoceanography, Cretaceous and Cenozoic climate). One of the ways that the UK exerts its influence is via Site Survey funding from the UK-IODP research programme budget. Site survey investigation information is essential to progress drilling proposals and funding for this must be found at the national level. Scientific leadership is therefore heavily dependent on funding for site survey data. 'Virtual' site surveys, where pre-existing (often industrial) seismic data are utilised for surveying a drilling target location instead of commissioning a research cruise to take new seismic data, are exceptional value for money and are an area in which the UK has a strong track-record internationally.

The panel also considered the issue of coherence, coordination and connectivity of UK ocean drilling research. There were fewer positive responses to the consultation on this subject, rather split between those who responded that indeed UK-IODP is well-organised and has tried hard to broaden the community via workshops/symposiums, and those who responded that this coordination was at an administrative rather than scientific level.

[11] A further UK scientist has just been approved as a co-chief and so the UK will have had co-chiefs on ~12% of expeditions by 2013.
[12] INVEST organized a large, multidisciplinary, international community meeting in 2009 (attended by ~600 participants), whose focus was to define the scientific research goals of a post-2013 ocean drilling program.
[13] ECORD Science Support and Advisory Committee

The programme is especially well aligned with the Earth Systems Science theme and also contributes to the Climate System and Biodiversity strategic NERC science themes as well as the People and Partnerships themes. The panel also heard evidence of the development of technology which addresses, but is funded independently of, the Technologies theme.

The IODP makes a significant contribution to NERC strategy and certainly provides national and international scientific leadership while supporting a world class environmental science community. It makes important contributions to a number of the NERC science themes. It is important to note that this level of scientific output and quality crucially relies on the level of participation in the programme, because the high-profile science output inevitably arises from participation onboard the drilling vessels and access to data and samples during the moratorium period of 1 year after the completion of a drilling programme during which cruise participants have priority.

'Position paper 2' in the panel's papers (see **Annex I**) was written by and endorsed by members of the UK-IODP Programme Advisory Group and details how the science tackled by IODP aligns with NERC strategic priorities. Contributions to the evidence from NERC Theme Leaders assert that IODP underpins knowledge of the longer-term evolution of climate, with palaeoclimate and evolution of the Earth System being of crucial relevance to the Earth System Science as well as Climate System themes. Alternative sources of data such as ice cores and piston coring tackle only shorter-term and much more recent climatic change, only long cores of ocean sediments can provide high resolution long time scale records. The long piston coring capability available on research ships, such as the RV Marion Dufresne, is complementary to IODP but cannot offer the length of core penetration and high quality of IODP coring.

The major contribution to the Biodiversity theme is in terms of the discovery and study of the deep biosphere. 'Position paper 2' showed that IODP drilling aligns well with NERC Strategy. However, this paper somewhat overstates the claim that IODP addresses all the themes (e.g. the methane hydrates expedition is in the panel's view, more aligned to the Natural Hazards theme and not the Sustainable Use of Natural Resources theme). Thus, the mapping against themes was considered to be helpful and generally valid but not definitive. The panel noted that although the programme aligns well with the current NERC Strategy it is important to record that the lifetime of the successive ocean drilling programmes (i.e. the Deep Sea Drilling Project (1968-1983), the Ocean Drilling Program (1983-2003) and then IODP (2003-2013)) has been much longer than that of any past specific NERC strategy. Hence the relevance to the current NERC strategy is important but not the only criterion. The IODP has been relevant to past NERC strategies and the current strategy, and is likely to be relevant to future strategies. As long as climate change and the functioning of the Earth system remain important issues, IODP research will have high relevance and impact. The over all support for the programme was shown in the tailored statement provided by the Geological Society of London which details the wide number of significant scientific breakthroughs that the programme has accomplished, including those directly related to NERC science Strategy.

It was noted that the NERC Leader of the Technologies theme did not recognise the input of IODP to this theme. However the panel believes that such an input has and does occur because the technology development reaches users directly without the mediation of the Technologies programmes. Technology development funding is therefore almost certainly being accessed via routes other than the Technologies theme budget (e.g. a sea-floor riser drilling system was developed with the direct funding from IODP's central management organisation (IODP-MI) along with a significant amount of funding from industry). Thus this stream of NERC Technologies theme funding can be used for other areas that need this fundamental catalyst for development. This is yet another example of extra leverage for the UK in terms of IODP investment.

The technological impacts made by the ECORD Science Operator (ESO), which is responsible for undertaking Mission Specific Platforms (MSPs) operations and is led by the British Geological Survey, were highlighted. ESO's enhancement of NERC capacity was also noted by the panel, as was the UK's central involvement in the technology developments utilised in ECORD MSPs.

The programme also delivers well against the NERC Organisational Strategic themes of People and Partnerships. Evidence gathered after the panel meeting indicates that there are more than 100 PhD students[14] in the UK who have been working on IODP samples and data. One piece of anecdotal evidence from a single, large UK geosciences university department shows that around 80% of students rely on IODP material for their research. Interview evidence indicated that the UK community is far healthier now compared with 10 years ago at the start of IODP, with an increasing pool of people involved. The training and networking opportunities that IODP provides is inherently greater and more international than that available from any other cruises or programmes. Evidence demonstrates that the international links forged during an expedition continue for years and decades into the future.

The questionnaires elicited very positive responses in terms of partnerships and new collaborations formed as a result of the UK's involvement in IODP. These were mainly with the US and Japan, although a significant number of new opportunities with European colleagues were also noted. There was a perception on the basis of some of the questionnaire responses that in the UK, programme funding tends to be concentrated amongst the same, and small number of academic groups, indeed the same names tend to be cited amongst a lot of the evidence gathered for the review. Both the academic and user communities felt that the programme could be better at facilitating the involvement of more peripheral groups, and also at facilitating inter-disciplinarity in the scientific community.

The panel has seen clear evidence that UK-IODP develops an excellent group of trained post-graduate and post-doctoral researchers that is highly valued by academia and industry. The exceptional networks developed by IODP are very important to the career development of this group.

Data gathered from a UK geosciences community survey indicates in excess of 100 PhD students in UK institutions who have used IODP data and samples since 2004. It was estimated that for every senior researcher working on IODP material, there are at least two students also involved in the programme. Reponses from the wider academic and UK-IODP community emphasised the strength of training for students and early career researchers. Two quotes taken from questionnaire responses which illustrate this are: "This is one of the real strengths of IODP. Participating in IODP has started many successful research careers as well as providing essential data, samples, publications and collaborations for a large number of PhD students"; "Participation in drilling expeditions and post-cruise science gives students and young scientists an unparalleled chance to interact with a broad international group of researchers". Responses also emphasised a particular strength of UK-IODP and IODP as being the mix of young early career scientists/post-graduate students with many more senior scientists on research cruises and the opportunities this presents. Such interaction is also facilitated by UK and European related IODP activities such as UK-IODP meetings, ECORD Summer Schools (which UK-IODP funds around 6 post-graduates to attend annually), EuroForum[15] and other specific meetings and workshops (IODP-MI and European Science Foundation's Magellan[16]).

[14] Of which only 15 were funded directly by the UK-IODP Research Programme

[15] http://www.essac.ecord.org/index.php?mod=workshop&page=euroforum

[16] http://www.esf.org/activities/research-networking-programmes/life-earth-and-environmental-sciences-lesc/current-esf-research-networking-programmes-in-life-earth-and-environmental-sciences/workshops-on-marine-research-drilling-magellan-workshop-series.html

A significant proportion of the questionnaire respondents from the community were early career researchers, who responded positively to the opportunities IODP provides. This underlines the level of support the programme has from this group of academics. UK-IODP was seen as a "career accelerator" for those post-graduates who get involved and the UK-IODP community was recognised as being very supportive of young researchers.

In relation to the research programme element of the programme, the panel discussed the relative balance between post-cruise, shorter and longer grants, summer schools and other meetings and recommended that UKIODP keep the post-cruise funding allocation under review and use it flexibly to ensure that researchers can secure sufficient funds to start to work up results post-cruise, particularly during the moratorium period.

It is clear from the feedback from industry (including panel interviews) that they make significant use of the data generated from IODP, particularly published literature and also archived samples

Interview evidence from the panel meeting shows that major petroleum companies are beneficiaries of IODP, primarily via data and samples used for rock properties: one user interviewee said he could name a dozen IODP drill holes worldwide that have been used as exploratory wells by industry using IODP cores to inform subsequent drilling activities and significantly reduce costs. Also, the ACEX Arctic drilling mission was important to industry in terms of technological developments in the use of ice-breakers and coring techniques in support Arctic drilling, which are now used by industry. The IODP data that industry make use of would be expensive for them to collect themselves, thus to UK Plc, the programme delivers value – for example, North Sea drilling cost several tens of millions of pounds per drilled hole, and in the Arctic, one industry mission would be on the order of the total cost of ACEX (i.e. $13M, excluding the cost of ice-breakers).

Comments received via the evidence-gathering questionnaires on the programme's relevance to users were more variable: one user commented that IODP had played an important role in enhancing the competitiveness and profitability of industry – especially through being able to request samples - which has resulted in improved biostratigraphic zonation schemes and source-rock characterisation; the Houston BP office has requested samples with a view to analyse total organic carbon, and reservoir data have been used to gauge the nature and location of turbidite systems extending into the deep sea off continental margins. Industry users are apparently particularly interested in results that may change their view of a specific area or basin (i.e. macro- rather than micro-scale) for which IODP data may be very useful. The programme's technology developments are also valuable to industry.

Some users commented that whilst information was shared well amongst the academic community, it did not spread outside to that of the user community. However, the majority of the user community who responded to the questionnaire regarded the programme's profile as high and those who thought the programme was poorly known (5 respondents) were restricted to certain areas of science.

Interview evidence noted that the support for the programme from industry probably varies, with the main endorsement coming from the larger petroleum companies (e.g. BP, Exxon, Chevron, Total) who have wider foci and more time to engage, and generally restricted to the exploration arms of the companies, with production experts and smaller exploration companies (not surprisingly) less supportive.

The programme's knowledge exchange achievements were not as highly rated by the academic community for reasons that the panel has not been able to identify.

The panel recognised that UK-IODP deserves praise for its efforts to interface with users and other stakeholders and acknowledged the important (but un-quantified) output from trained personnel going into industry, government, etc.

Measuring economic impact is difficult because much of the benefit of the programme could be perceived as 'indirect' via publications, trained personnel, etc. The user 'dialogue' and qualitative evidence is the strongest evidence supporting the statement that there is significant impact at this level. Furthermore, the impact to industry is cumulative, as was demonstrated during interview, by its stated access to data and stored cores during interviews. However, definitive documentary evidence for these activities is not currently available because of a lack of records documenting such access. The cumulative nature of the database of resulting impact that is useful also precludes an assessment of the relationship of impact to science in any short timescale.

Relative to the overwhelmingly positive responses recorded in the questionnaires in all other areas overall, some weaknesses were identified with regard to knowledge exchange. However, the panel felt that many of these weaknesses are undoubtedly generic to research more generally and are not unique to IODP, and it was recognised that there are difficulties in quantifying the impact of enabling collaborations.

Compared to the US's IODP programme, the UK-IODP does not engage in a large amount of outreach activities with wider society (schools, public etc.), although the panel could not ascertain whether investment in this kind of activity would actually increase value for money from the research significantly. The programme's performance appears to be patchy in terms of engagement with users and other stakeholders, but there have been highlights, such as the input to IPCC (e.g. especially to Chapter 6 of the report of Working Group 1 in the IPCC AR4 of 2007[17]). The programme's role in delivering key science with impact indirectly was also recognised by the panel – for example, as enabling the palaeo-science that will support the policy objectives of the UK Ocean Acidification research programme (which is co-funded with the UK's Departments for Environment, Food and Rural Affairs (Defra), and Energy and Climate Change (DECC)).

Having considered the available evidence, the panel concluded that that UK-IODP research programme may not be "selling" itself effectively to the wider community to ensure that its contributions are more widely understood and appreciated sufficiently. In the future there is a need for the research programme to try to capture quantitative impact data more effectively.

The panel was concerned about the recent reduced level of activity of the Industrial Liaison Panel (ILP), but applauded its expansion from the UK into the European Consortium for Ocean Research Drilling (ECORD).

The mechanisms for transfer of knowledge have traditionally been focussed on the oil and gas industries via the Industrial Liaison Panel (ILP). The panel noted that the ILP had not been as active as it had been earlier in the programme despite the obvious continued commitment of its chairman (who was interviewed by the panel). The IODP as a whole is trying to engage more with the petroleum exploration industry, and the expansion of the UK-IODP ILP into an ECORD ILP may aid broader engagement and facilitate greater activity. The new ECORD ILP offers an opportunity to change this for Europe in the future programme and the way the programme is structured.

A more targeted approach has been initiated with industry and following consultation the ILP will now focus on enabling industrial collaboration(s) with Mission Specific Platforms in the Arctic. A specific

[17] http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch6.html

target of this kind, which is of both scientific and commercial interest, will undoubtedly stimulate industry-IODP interactions; thereby providing a stronger engagement than the more generic approach of the past has enjoyed. The panel welcomed the new approach that has been taken by the ILP and recognised that it remains extremely challenging to engage with industry on basic research, especially at times of economic pressure and competing priorities.

3. TERM OF REFERENCE TWO

Term of Reference 2
Advise on the potential future benefits and value for money from the UK's continued involvement in ocean drilling and its potential to deliver NERC strategic and science priorities

Since the second Term of Reference focuses on future involvement in the ocean drilling programme post-2013, the panel's primary sources of evidence for its deductions have been the track record of the current programme and the ocean drilling that will arise from the drill proposals that are already in the IODP system. Because IODP has such a well-planned system for development of these proposals, the panel felt that it had a reasonable understanding of what will be delivered in the first few years of the new programme. This section of the report is divided into the topics of discussion around which the panel's agenda was organised.

Based on the evidence presented, the panel considers that successive ocean drilling programmes have continued to be highly effective and relevant notwithstanding numerous changes of NERC strategy, and the panel expects that to continue. The panel strongly advises that future NERC investment in the ocean drilling programme post-2013 should be such as to enable the UK to continue to achieve NERC's strategic goals from a sustained leadership position. The NERC subscription to the new programme will be determined by international negotiation over which the panel has no control, but the panel recognises that there will be an investment threshold below which the UK will lose its disproportionate benefits. This threshold may be similar to or slightly less than the current subscription of $5.6M per annum. It is recommended that an associated research programme should be maintained in order to maximise the benefits from the subscription, and the panel judged that this can be achieved with a similar level of funding to the UK-IODP research programme (i.e. £7m over 5-years).

3.1 Science Achievements

On the basis of past achievements of the programme, the panel expects that novel scientific discoveries will emerge from the activities of the UK within the future programme.

The panel considers that there is strong evidence from past activities that the programme is achieving major scientific breakthroughs and that this should continue in the future (also sees **Section 3.2**). Examples of IODP's strong track record in major scientific advances involving UK scientists include: the first deep sea research drilling in the Arctic Basin that demonstrated the presence of warm and fresh (low salinity) water in the lower-middle Eocene and the onset of cold conditions by mid-Eocene; the first drilling of a continuous section through intact oceanic crust to reach lower crustal gabbros provided information on the magmatic and hydrothermal processes that control solid earth-ocean geochemical changes; and the first complete coral record of last deglacial sea level rise from a tectonically stable region. The programme's delivery of well - conceived research also continues to throw up unanticipated

novel scientific discoveries. Examples of which include: the discoveries of the deep biosphere and the Arctic freshwater lake; the extent and rapidity of the Palaeocene-Eocene Thermal Maximum (PETM) thought to be key in understanding global temperatures, related high atmospheric CO_2 levels and oceanic behaviour during "hot-house" periods, and the inception of large-scale glaciation.

Ocean drilling is effectively still in the exploratory phase and the Panel found no evidence that IODP is repeating missions or that the current modus operandi generates inefficiencies. The panel were in full agreement that the current focus of the programme on data collection is important and appropriate. Whilst cores capture only a small spatial coverage and are necessarily site-specific, it is premature to move to an approach that relies more heavily on the use of legacy data and/or models to tackle key scientific questions in many areas. For example, there is still a need to collect baseline data in order to understand processes such as deep earth hydrothermal plumbing.

Knowledge of the functioning of the Earth system in the past is still so rudimentary that it must be recognised that there is a critical need for the exploration science of IODP, especially where we can anticipate discovering environments with no contemporary analogue. The panel considered that the novel scientific discoveries delivered by the new programme will be of major importance to the delivery of the NERC Earth System Science theme, and of importance to the delivery of several other NERC science themes.

It was noted that the high quality outputs from the UK's involvement in IODP – both now and in the future – rely upon the level of the UK's participation in the programme, because high-profile science outputs invariably result from participation onboard the drilling vessels and the access this provides to samples and data during the post-cruise one-year moratorium period.

3.2 UK Representation and Leadership

There is strong UK representation in up-coming drilling proposals. This planned IODP activity in the next five to seven years should lead to exciting scientific advances by UK scientists in areas including climate change (higher spatial and temporal resolution data); understanding deep ocean crustal structure; the biogeochemical functioning and biodiversity of the deep biosphere.

The existing associated research programme (including site survey investigations) should continue in order to capture benefits from investment in the subscription. The panel notes the potential for accessing pre-existing, mostly industry, geophysical data as a very cost-effective mechanism for 'virtual' site surveys, where the UK is a world leader. The evidence is that the present level of research programme investment is leading to high quality outputs.

With the use of sea floor rock drills as Mission Specific Platforms (MSPs), there is an opportunity for British Geological Survey to play a further leading role in addition to its current function as ECORD Science Operator.

The panel is confident that there are emerging leaders of the UK-IODP community who will maintain the UK's international profile.

Site surveys funded by the UK-IODP research programme have helped the UK science community have strong involvement in, and leadership of, a significant proportion of the up-coming drilling proposals

that are in the IDOP system. This strong representation is demonstrated by the UK having a disproportionately large number of proponents of active proposals amongst: (i) ECORD[18] members, where the numbers of proponents based in the three main ECORD member countries, the UK, Germany and France, were 103:78:61, respectively[19]; and (ii) international members, where the numbers of proponents from the UK, US, Japan and other countries were 103:248:131:487, respectively, which means UK scientists are proponents of 10% of all proposals that may be drilled in the next five to seven years.

Since the developing plans for IODP drilling are known many years in advance it was possible for the panel to deduce what is likely to be studied in the first phase of the post-2013 programme, even if it is not possible at this early stage to know exactly what is delivered. Important future targets and achievements were identified in the up-coming drilling proposals, in particular the panel noted in evidence that future research should lead to exciting advances in areas, such as: climate change (especially provision of high-resolution data with which to test present and future models); understanding of deep ocean crustal structure; the genetic element of deep biosphere microbiology; the exploratory element of riser drilling of subduction zones; enhanced sea level data (especially on shorter, more societally-relevant timescales); and, understanding of high-latitude processes during glacial and de-glacial climates. In addition, it was noted that an important delivery challenge in the future programme for ECORD will be further scientific exploration of the Arctic Ocean Basin.

Looking to the future, the panel strongly advises that NERC's future investment in its subscription post-2013 should be such as to enable the UK to continue to achieve NERC's strategic goals from a sustained leadership position. Whilst the international negotiations are still on-going between funding agencies, the panel recognises that there will be a subscription investment threshold below which the UK will lose its disproportionate benefits and this threshold may be similar or slightly less than the current subscription of $5.6m per annum. If NERC meets this threshold then the UK influence and international leadership should be maintained and the value for money from the UK's continued involvement in ocean drilling should remain very high. The panel also advises that there is strong evidence that the present level of investment in the UK-IODP research programme (with £7m over 5-years) is leading to high quality outputs and that an associated research programme should be maintained post-2013 in order to maximise the benefits from the subscription. The panel judged that this can be achieved with a similar level of funding to the current research programme.

It is recommended that a future research programme should continue to provide for the timely exploitation of new drilling (for example by awarding post-cruise grants and 'directed' standard grants) and the continued strong support for site survey investigations to maintain the UK's strong influence on the development of future active drilling proposals. The panel were particularly impressed by the unique 'virtual site survey' grants developed by UK-IODP (see also p.6), often in partnership with industry, which utilised non-IODP sources of geophysical data on drill sites that required evaluation before drilling proposals could proceed through the IODP system. This is a highly cost-effective way of enabling UK researchers to develop drilling proposals without the need for dedicated expensive site survey cruises, and it is recommended (resources permitting and where appropriate) that these grants continue to be funded. Indeed the input from the Geological Society of London notes that "significant secondary benefits derive from the site survey programme underpinning the selection of IODP drilling sites, using geophysical and ocean floor sampling methods. The data gathered through this work complement

[18] European Consortium for Ocean Research Drilling, which represents 16 European countries and Canada.
[19] As of July 2010

those arising from the drilling programme itself, helping to build the breadth and depth of the geological evidence base informing our understanding of past events and processes, and of future natural hazard risks and economic opportunities".
It was noted that there may be a case for NERC adjusting post-cruise grants to provide for at least 6-months PDRA funding and directing UK-IODP standard grants more towards research on recently collected samples (e.g. samples within the moratorium period), whilst relying more on responsive mode to support research on older samples. It was also noted that there may be an opportunity in future to actively strengthen the UK's engagement with the activities of the Japanese riser drilling ship, Chikyu (see **Term of Reference 3** for more details).

The panel recognised the strong leadership provided by the British Geological Survey (BGS), and the benefits this provides to the UK's national capability, in its effective implementation of Mission Specific Platform activities (as part of its ECORD Science Operator function) and in its development of state-of-the-art sea floor rock drilling technology – which fits with both IODP and NERC strategic objectives. The development of sea floor rock drilling systems could be instrumental in changing the way that ocean drilling work is delivered in future – for example, these systems could make a critical contribution to Arctic missions in ice covered regions via their deployment/recovery through an ice-breaker's moon-pool (i.e. a hole through the body of a ship). Proposals by ECORD to develop and maintain a rock drilling facility for Europe are welcome and the BGS is in a position to take a strong leadership role in its development. There is currently both scientific and economic pressure to develop this capability, but if in future the BGS no longer supports IODP scientific operations (i.e. via ESO) there then may be a case for the BGS rock drill being developed primarily as a capability used in support of requirements of commercial work under contract with industry.

The panel is confident that the UK's international profile should be maintained in the post-2013 programme as there are emerging leaders of the UK-IODP who will in time take over from some of the more senior scientists, who have provided excellent leadership under IODP. A real strength of IODP is that it enables early career scientists who have been on cruises to work closely, and network, with senior scientists from many countries. The panel felt that more earth science community engagement activities within the UK could be beneficial in building the wider UK community. One model might be that used in Germany where annual symposiums are run for past and planned expeditions' participants to share experiences and scientific discoveries. This could be rolled out in the UK in departments across the UK, which would also lead to the involvement of more peripheral research groups.

3.3 Delivery against NERC Strategy

The panel anticipates that IODP will continue to deliver effectively against NERC Strategy – both the science themes and the People and Partnerships organisational themes – and has the potential to contribute substantially more towards the Natural Hazards and Sustainable Use of Natural Resources science themes than in the past.

The already planned activities of IODP should particularly contribute to NERC's aspiration to expand its research in the Arctic.

The Panel would advise continued use of UK-IODP as a very effective vehicle for graduate training.

Recognising NERC's commitment to improving fundamental understanding the planet, the panel recommends that NERC maintains its support for all the elements of ocean drilling programme's research. This includes cutting edge science which is not obviously directly societally relevant in the short term – for example, investigation of the deep biosphere. The panel's finding, based on the evidence presented, was that successive ocean drilling programmes have continued to be highly effective and relevant through numerous changes of NERC strategy, and the panel expects that to continue in future.

As noted earlier (see p.7-8) the IODP is especially closely aligned with the NERC Earth System Science (ESS) theme, where it is central to the delivery of ESS Challenge 2, and the NERC People and Partnership organisational themes. It also makes a significant contribution to the Climate Systems and Biodiversity themes.

Looking to the future, there is strong overlap between the existing NERC strategic science priorities and the new ocean drilling science plan for the post-2013 programme, which has been developed with strong input from the UK community. For example, the new science plan includes a strong emphasis on: co-evolution of life and the planet (including deep biosphere); climate change (including ocean acidification and carbon cycling; and the role of ice sheets in past and future sea level change), and geo-hazards (including earthquakes, landslides, tsunamis). Post-2013 there is also the potential for additional important contributions to the Natural Hazards and Sustainable Use of Natural Resources themes via further development of rock drills to recover surficial sediments and providing information about exploitable mineral development and locations. Improvements and advances in Chikyu drilling is also likely to lead to major advances in terms of seismogenic zone exploration, origin of earthquakes, exploration of unstable areas such as zones of gas hydrates etc. In order to maximise the return from UK involvement, more engagement at a higher academic level with the Chikyu drilling programme may be appropriate at some point in the future. This could be very cost-effective, as any UK investment in this area would be extremely modest in comparison with that of Japan.

One of the main foci of the Mission Specific Platforms in the next 10-years will be on the Arctic, and planning is already underway to deliver the required site survey investigations. Planned activities will include coring areas that target climatically important regions of the Arctic, as well as sites that will improve understanding of tectonics and climatically sensitive storage and release of gas hydrates. The delivery of these missions will undoubtedly contribute to the delivery of NERC strategic science and will make a major contribution to NERC's aspiration to expand its research in the Arctic.

There is good evidence that there is currently a healthy pool (which has grown over the past ten years) of UK scientists who can contribute to the UK's ability to deliver strong international leadership in the future. Equally, there is a cadre of well-integrated early career scientists whose energy and enthusiasm are palpable and this should ensure that future activities continue to make a strong contribution to the Partnerships theme of NERC Strategy. Evidence for this includes the fact that of the 13 members of the international writing group that was responsible for the new post-2013 IODP science plan, 3 members[20] were from the UK – one of whom was responsible for chairing the group.

The panel considers that IODP has a strong track record of training of the next generation of UK scientists with, for example, over 100 UK based PhD students being provided with access to cruise

[20] Prof M. Bickle, (Univ. Cambridge, and Chair), Prof H. Palike (Univ. Southampton) and Prof D. Teagle (Univ. Southampton)

berths and/or IDOP data and samples since 2004. There is also clear evidence that an international network of scientists has built over the years that early career scientists can easily tap into and use to take full advantage of the opportunities that arise from this major international programme. There is the potential to further enhance this training by providing NERC-funded early career scientists (both post-graduates and post-doctorates) with an opportunity to meet together on an annual basis – this could, for example, be run in the UK along similar lines of the Urbino Summer School[21]. In addition, the panel noted that industry had identified considerable potential for the training of co-funded CASE studentships in areas of IODP science that converge with industry interests.

3.4 Knowledge Exchange and interactions with industry

The UK-IODP community could do more to engage more widely in knowledge exchange (KE) activities but they need help and facilitation from the dedicated KE group within NERC.

Evidence acquired from industry demonstrates that they want to engage with IODP. This may be best done by involvement in specific activities and would do this best initially around a focused research programme in the Arctic. On that basis the panel is reassured that in the future programme's funding model, interaction and co-funding with industry (especially in Europe via the ECORD Industry Liaison Panel) may be easier.

The panel has heard evidence of industry's enthusiasm for drilling in the Arctic.

Industry also expressed enthusiasm for the potential use of CASE studentships, because they were concerned about the supply of a trained workforce.

The panel acknowledged that the UK-IODP community has made efforts to improve knowledge exchange (KE) but this is difficult even within a long lived programme where there is more time to develop KE activities. The panel notes the recent central NERC investment in developing KE activity and suggest that the UK-IODP programme works closely with this team to benefit from their expertise and focus on this area.

The NERC KE teams (including personnel within UKIODP) need to do more to engage with industry at a broader than programme level initially, especially with business and technology, although IODP should not ignore the non-industrial community (including government). In particular IODP needs to do further work in specific areas of science related to, and in the interests of, industry. One example of this is the Arctic and the panel welcomed the ECORD Industrial Liaison Panel's (initiated as the UK ILP) plan to organise an Arctic conference in 2011 with industry as a means to facilitate the development of partnerships to deliver future Arctic Mission Specific Platforms. The panel heard from industry representatives[22] that there would be strong interest in such partnerships from the major oil companies (BP, Exxon, Total, etc), building on existing activity by industry in the Arctic (e.g., explorations on the East Greenland Shelf (STATOIL) and West Greenland Margin (CAIRN Energy)), although smaller companies may have less interest as the focus of their operations is necessarily more narrow and they have less resource and time to engage. A specific target of this kind, which is of both scientific and commercial

[21] http://www.urbinossp.it/

[22] Richard Hardman (Independent), Mark Thompson (BP)

interest, will undoubtedly stimulate industry-IODP interactions, thereby providing a stronger engagement than that provided in the past by a more generic approach.

It was recognised that it is extremely challenging to engage with industry on basic research, especially at times of economic pressure and competing priorities and with financial contributions from industry direct to the programme, a reciprocal influence would be desired. Other issues include security of data. However, one practical option would be industry-sponsored PhDs on certain topics of interest. There is a concern from industry that there is a current dearth in trained young earth scientists emerging, so indeed, industry-sponsored PhDs could also be a method to tackle this issue.

In general UK-IODP deserves praise for its interface with users but the panel would be interested in a follow-up exercise looking at the effectiveness and value for money of activities like producing and circulating the Arctic brochure, expanding the outreach activities etc. NERC needs to find a way of capturing the added value of KE activities in a quantitative way. In general, the Geological Society of London notes that "The social and political significance of science emerging from deep ocean drilling is only now becoming apparent, and its economic impact is underappreciated".

4. TERM OF REFERENCE THREE

Term of Reference 3
Advise on the relative priority for UK science of the three IODP platforms in the future ocean drilling programme.

The review panel's views on the relative priorities of the three IODP platforms were particularly informed by position papers submitted by the UK-IODP Programme Advisory Group, and by evidence provided in the other evidential documents (including the questionnaire responses) and by the interviews.

Having reviewed the evidence, the panel recognises that all three present platform types (riser drilling - Chikyu, non-riser drilling - JR and Mission Specific Platforms - MSPs) provide complementary and unique sea floor sampling opportunities. The panel considered the best way to prioritise the NERC investment across the three platforms is: to maintain a balanced portfolio between MSP and JR operations and encourage IODP to realise the Chikyu's potential on the global stage in the next five years. Specific suggestions are made about the nature of the balanced portfolio and the potential of the Chikyu.

The panel's primary source of evidence was provided by two position papers, submitted by the UK-IODP Programme Advisory Group, that specifically addressed the panel's third Term of Reference – to advise on the relative priority for UK science of the three present platform types (riser drilling - Chikyu, non-riser drilling - JR and Mission Specific Platforms - MSPs) in a future ocean drilling programme. These two position papers made the cases for the JR[23] and for the MSPs[24] (see **ANNEX I**), respectively, being the priority platform for UK membership of a post-2013 ocean drilling programme. In addition to these sources of evidence, the panel heard evidence from a number of members of the science community (see **Annex II**) and considered evidence that was provided in some of the panel's other review papers and in the 'review questionnaire' responses.

Based on the evidence received, the panel was convinced that the three platforms provided complementary capabilities and unique sea floor sampling opportunities to deliver globally significant science with little or no duplication of effort.

With regard the JR and MSPs, the panel concluded that there are irrefutable scientific arguments as to why both capabilities are needed in a future ocean drilling programme because each provides access to samples and areas of the seafloor that the other cannot, yet, and are of high priority to the community. Whilst MSPs have provided a new capability under IODP that allow for drilling in shallow waters (including coral reefs) and in the ice-covered waters of the Arctic, the JR has continued to provide the complementary longer and deeper water cores that have been the mainstay of the drilling programme (IODP, ODP, DSDP) since its inception.

[23] IODP Rev 2010/10 Position Paper 3: Platform Priorities - Ocean Research Drilling and the Joides Resolution (JR)
[24] IODP Rev 2010/10 Position Paper 3: Platform Priorities – Ocean Research Drilling and Mission Specific Platforms (MSPs)

With regard the Chikyu, the panel considered that the riser drilling has the potential in the medium term to provide unique access for the UK community to both very deep parts of the oceanic crust (that allow for the testing of theories of deep earth science, including deep biosphere) and active tectonic settings relevant for societally-relevant natural hazard research – for example, by the drilling, sampling and instrumenting of the seismogenic portion of a plate-boundary fault off the coast of Japan. The Panel noted that it had not received a position paper in support of riser drilling, and this was taken as being evidence that the case for riser drilling in the UK community was not as strong as that for the other two platforms. This was supported by other evidence, such as the fact that for the Chikyu's first five cruise legs there were relatively few UK applications for berths – with only 16 participation applications from UK researchers (84 in all from ECORD) of which 13 were PhD studentships and one for a post-doctoral researcher. It was noted that there had been a UK Chikyu Co-Chief on one of the Nantroseize legs[25].

Having considered the evidence, the panel felt that whilst the UK community had not yet fully taken advantage of the potential of riser drilling, it was not clear to what extent this reflected either some gaps in the UK academic research base or the fact that the current geographic areas of deployment of Chikyu did not align with the interests of a strong academic base in the UK. In the longer term which of these two circumstances are correct matters because there is a real opportunity in the post-2013 programme for a step-change in the UK's involvement with the Chikyu's activities. For this potential to be realised it will be vital that the Chikyu completes the timely delivery of its current science programme on the seismogenic zone off Japan. This will then need to be combined with the deployment of the Chikyu away from the region around Japan to deliver a programme of global activities, including those planned in the Mediterranean Sea in the post-2013 programme. This offers greater opportunities for the UK community in fields such as deep earth structures and geo-hazards research to strengthen their engagement in future Chikyu activities.

In considering the relative priority of the platforms, the panel felt that there was no strong scientific argument that would justify directing funding away from MSP activities to increase the operations of the JR from the 8-months per year (characteristic of the recent past) to 12-months per year. The panel recognised that there may be a valid financial argument to do so, but in the absence of accurate financial information on the additional marginal costs of moving to year-round operations of JR, the Panel could not fully evaluate the issue. In any event, the panel considered that there was compelling evidence to maintain MSP operations at least at the current level of activity (i.e. approximately one MSP every two-years), even if this precludes 12-month operations for JR. This conclusion is driven in part by the scientific benefits that can be delivered by MSP operations. For example, the future focus of MSP operations in the Arctic, where it is the only viable mechanism of exploration, would help in the delivery of NERC's priority for Arctic research. However, there is a second driver which is the strong enthusiasm shown by users (the major oil companies) for partnerships in this area, and by the strong UK technical capability. It was considered that there was likely to be substantial long-term benefit through increased collaboration with industrial partners.

The panel recognised that Europe, and particularly the UK (British Geological Survey), are international leaders in sea bed drill operations. These operations place a drilling base on the sea bed directly and allow more precise drilling. This has substantial benefits in some areas and permits activities on sites which the JR cannot access. The panel welcomed the moves by ECORD to utilise these facilities in the future in order to allow MSPs to provide access to unique surficial sediment sampling opportunities. Looking forward, the use of sea bed drills in this way would be particularly relevant to the delivery of the NERC 'Sustainable Use of Natural Resources' theme – in particular sub-sea mineral resources and possibly gas hydrates, and this is also likely to be of interest to industry and the Natural Hazards theme.

[25] http://www.jamstec.go.jp/chikyu/eng/Expedition/NantroSEIZE/index.html

Having considered all of the evidence, the panel concluded that the priority for the NERC is to maintain a balanced portfolio between JR and MSP operations, whilst encouraging IODP to realise the Chikyu's potential on the global stage in the next five years.

ANNEX I

List and description of papers received by the review panel

Agenda *Outlines the structure of the panel meeting on 6-7th December*
Panel Terms of Reference *Lists the Terms of Reference for the review panel*
Panel Membership *Lists the members of the review panel*
Review Background, Objectives and Methodology (this paper) *Provides the reasoning behind the review, details of the methods used to collect evidence and convene the panel and the timetable of activities*
Introduction to IODP and UKIODP *Details the background and structure of the international IODP, the management structure, available funding and relationship of the UKIODP to the international programme. Includes a summary of each of the IODP Expeditions to date.*
Synthesis of Questionnaire Responses *An impartial summary of all the points raised in the community evidence questionnaires divided into key topics and themes*
Evidence Matrix *A cross-referencing metadata tool tabulating the main sources of evidence in the review papers for each key topic and theme*
Position Paper 1: View of IODP and UKIODP *A position paper providing information on the international and national programmes to date and endorsing their achievements and the UK's involvement.*
Position Paper 2: Delivery of NERC Strategy *A position paper outlining UKIODP's role in delivering key components of NERC Strategy aligning (UK)IODP's science delivery with relevant Theme Actions.*
Position Paper 3: Platform Priorities *Two position papers championing two of the three drilling platforms, .in direct response to the third Review Term of Reference ("Advise on the relative priority for UK science of the three IODP platforms in the future ocean drilling programme").*
Position Paper 4: Financial Contribution *A position paper written by the Chair of the UKIODP Science Advisory Group indicating the repercussions of financial cuts to the UKIODP Subscription and Research Programme.*

UK IODP Budget Summary *A spreadsheet detailing future programme financial allocations and expenditure to date.*
Evidence Metrics Summary *Full summary of the listings of publications, expedition participation, co-chiefs, national and international panel representation, UK affiliated proposals, sample repository access requests, media and outreach activities, and ECORD summer school participation. Full lists can be found in Appendix F.*
NERC UK IODP Evaluation Report 2007 *The report and recommendations resulting from the UKIODP interim review carried out in 2007 to inform the renewal process for the second five years of the UK programme.*
Questionnaire Templates *Blank templates of the three evidence-gathering questionnaires that were circulated to the community as part of the open call for evidence to inform this review.*

Appendices

Background paper to the 2007 UKIODP Review *Summary paper providing information on the international and national programmes to date and endorsing their achievements and the UK's involvement. This was written for the 2007 interim review and is the equivalent document to IODP Rev 2010/08*
Detailed Summary of all IODP Expeditions 2004-2010 *Summary of scientific objectives, achievements and UK relevant of all IODP Expeditions completed to date.*
UKIODP Community Responses (spreadsheet) *Compilation spreadsheet of all the 52 UKIODP community response questionnaires*
Wider Academic Community Responses (spreadsheet) *Compilation spreadsheet of all the 24 wider academic community response questionnaires*
User Community Responses (spreadsheet) *Compilation spreadsheet of all the 13 user community response questionnaires*
Full Evidence Metrics *All evidence metrics:* 1. *UKIODP Grant funding* 2. *List of UKIODP-related publications* 3. *UK participation in IODP Expeditions* 4. *Active IODP proposals with UK proponents* 5. *IODP-related studentships* 6. *Core repository access statistics* 7. *Media and Outreach activities* 8. *UK membership listings of IODP panels* 9. *Comparison of UK publication outputs between IODP and equivalent UK programmes*

Industrial Liaison Arctic Brochure

Brochure produced by UKIODP in response to advice from the Industrial Liaison Panel to focus industry involvement on specific targets, initially, namely Arctic drilling.

ANNEX II

Panel Interviewees and their relationship to IODP

Prof Mike Bickle

Professor Mike Bickle graduated from Cambridge with a degree in natural sciences, completed a DPhil at Oxford, and had his first teaching post in Perth, Australia after post-doctoral fellowships at the University of Rhodesia and the University of Leeds. He returned to Cambridge in 1983 where he now has a personal chair in Earth Sciences. Professor Bickle is distinguished for his major contributions to understanding the evolution of the Earth through geological and geochemical research. His work includes pioneering studies on the thermal evolution of mountain belts, the tectonic and igneous processes that operated in the early Earth and studies of the geochemistry of rivers to evaluate the long-term fluxes to the oceans and long-term controls on climate.

His research combines field based, petrological and geochemical research projects with physical modelling in order to understand better the important processes which control global evolution. Most of the research has been related to tectonic processes within the solid Earth but most recently he has been working on solid earth-hydrosphere-atmosphere interactions. This work investigates the controls on long-term climate change through an understanding of river chemistry. The major long-term mechanism for removing carbon dioxide from the atmosphere is through weathering of silicates on the continents with the CO_2 transported by rivers to the ocean where it is deposited as a carbonate. Our research examines how much the erosive exhumation of the Himalayas is responsible for climatic cooling over the last 50 myr.

His other interests include the thermal evolution of mountain belts, the tectonic processes which operated in the early Earth, the physical processes which control melting within the Earth and determining the significance of fluid-flow in metamorphic rocks. His most recent work focuses on fluid-mineral reaction kinetics associated with geological carbon sequestration.

Role in IODP: Mike has taken a leading role in both IODP and UK-IODP since their inception in 2003. He wrote both the original UK programme case and the renewal bids that were presented to and supported by NERC SISB in 2002 and 2007. He has chaired the UK-IODP Science Advisory Panel and sat on the UK-IODP Executive Board since 2008 and sat on the UK-IODP Strategy Group and Steering Committee from 2003-2008. Mike has both chaired and been a member of the international IODP Science Advisory Structure Executive Committee (SASEC) and he was independently selected in open international nominations to chair the writing group for the New Science Plan for IODP's successor programme (post-2013).

Prof Gideon Henderson

Gideon is Professor of Earth Sciences and Associate Head (Research) of the Earth Science Department at the University of Oxford. Before taking up a faculty position at Oxford he was an Associate Research Scientist at the Lamont-Doherty Earth Observatory of Columbia University (US). He has a degree in Earth Sciences from the University of Oxford, and a PhD in Geochemistry from the University of Cambridge.

Gideon is a geochemist working to understand the long-term operation of the climate system and the role of ocean chemistry in the carbon and climate systems. His palaeoclimate research focuses particularly on the Quaternary and makes use of multiple archives (including marine cores, molluscs, and stalagmites) to provide high, sometimes seasonal, resolution information about the patterns and process of past change. This work strives to understand components of the climate system with particular relevance to the future, including changes in rainfall, sea-level, and ocean circulation. His

expertise in uranium-series geochemistry helps to place these palaeoclimate records into a precise chronological framework.

This expertise also provides information about the rates of process in the modern ocean. In this area, Gideon's research focuses on understanding the cycling of critical micronutrients such as Fe and Zn in the oceans, and on the calibration of proxies used to understand present and past ocean processes. He presently co-chairs the international programme on marine chemistry, GEOTRACES. He also co-directs the 21st Century Ocean Institute (part of the James Martin School for the 21st Century) with a remit to understand natural and human imposed changes in the marine carbon cycle during the present century.

Role in IODP: Gideon has been a member of the UK-IODP Science Advisory Panel since 2008 and also a member of NERC SISB since 2009. Gideon also received funding via UKIODP for his involvement in a EuroMARC site survey proposal related to the Tahiti Sea Level Mission Specific Platform (Expedition 310).

Prof John Ludden

John is the Executive Director of the British Geological Survey, which is the principal supplier of national geological capability for NERC and geoscience information for decision making for government, commerce and the public. He oversees all of the activities in the UK and internationally of approximately 750 people at three principal BGS sites in Keyworth near Nottingham, in Edinburgh, and Wallingford.

Before taking the post at the BGS, he was Director of the Earth Sciences Division at the CNRS, the French National Centre for Scientific Research. He served as Director of Research for the CNRS in Nancy, France, where he also taught at the French National School of Geology (ENSG-Nancy). Prior to this, Professor Ludden worked at the University of Montreal and with Woods Hole Oceanographic Institution in the USA.

John holds a doctorate in igneous petrology from the University of Manchester, UK. Among his responsibilities, Professor Ludden serves on the Board of IODP Management International and the advisory council of the EC Zero Emissions Panel (ZEP). He is appointed as a Visiting Professor at the University of Oxford and University of Leicester, UK and is a Research Director with the CNRS, France.

Role in IODP: John's role in IODP has been instrumental in both the UK and international programmes. Since 2008 he has sat on the UK-IODP Executive Board. John sits on the IODP- Management International Board of Governors and the IODP-MI Executive Committee.

Dr Richard Hardman

Richard Hardman is an explorationist and a qualified Geologist with over 40 years industry experience with oil majors including 10 years at BP, 11 years at AMOCO, 3 years at Superior Oil and 18 years at Amerada Hess. Since 2001 Richard has been working as a senior consultant to various oil and gas companies including Enterprise Oil, Neptune, FX Energy Inc and Atlantic Petroleum UK Limited. He is the former Chairman of both the Petroleum Group of the Geological Society and the Petroleum Exploration Society of Great Britain and the former President of the Geological Society. Richard was also a member of NERC SISB.

Role in IODP: Richard is the current Chairman of the Industrial Liaison Panel which was handed over to ECORD from the UK in 2009. Richard is also a past member of NERC SISB.

Dr Mark Thompson
Mark is a structural geologist and works for British Petroleum in their Exploration office. He has 33 years of industry experience, all with BP. Mark specialises in passive margin evolution and global deepwater exploration. His current position Exploration Excellence Team reviewing all exploration wells and new ventures worldwide, although is main international experience has been in Brazil, Egypt, Indonesia and Norway.

Role in IODP: Mark has been a member of the Industrial Liaison Panel since 2007 and the Deputy Chair of the panel since 2008.

Dr Tom Dunkley-Jones
Tom's research is concerned with understanding the evolution and controls on the Earth's climate during the Paleogene period, with a particular focus on the interrelationships between the biologically mediated marine carbon cycle and global climate. He has a particular focus on the response of low-latitude marine calcareous phytoplankton (coccolithophore) communities and surface ocean productivity to rapid global cooling across the Eocene-Oligocene boundary.

He's studied assemblages of calcareous microfossils collected from the Paleogene sediments of southern Tanzania, part of the Tanzanian Drilling Project. The Tanzanian microfossil assemblages have provided extraordinary new paleobiological information, including a doubling of the previously known global diversity of Eocene coccolithophores the discovery of previously unknown Paleogene lower photic zone coccolithophores and a study of the reliability of nannofossil proxy records.

In 2009 Tom sailed as a nannofossil palaeontologist on the Integrated Ocean Drilling Program Expedition 320 (March-May, 2009), one of two expeditions that form the "Pacific Equatorial Age Transect (PEAT)". The PEAT scientific program recovered an unprecedented near-continuous record of equatorial Pacific oceanography from the start of the Eocene (55Ma) to the present, and recovered complete Eocene-Oligocene boundary successions at four localities. His current position, funded by a Royal Society Dorothy Hodgkin Fellowship, will focus on producing records of calcareous phytoplankton productivity from these equatorial Pacific cores. He hopes to be able to integrate this data with carbon cycle and Earth System Model simulations to investigate the interplay between global climate, marine biogeochemical cycling and atmospheric pCO_2 across this critical climate transition.

Tom is a member of The Micropalaeontological Society committee as well as being a member of the International Nannoplankton Association, the Palaeontological Association and the American Geophysical Union. This year Tom co-chaired a day symposium at the third International Palaeontological Congress (IPC3), *The Micropalaeontological Record of Global Change,* and am convening a session at this year's AGU Fall Conference in San Francisco: *PP15. Reconciling Models of Hyperthermal Events in Earth History.*

Role in IODP: Tom sailed as a nannofossil expert on Expedition 320 as part of his PhD. He subsequently was funded via a UKIODP post-cruise grant to work on material recovered from the Expedition. Tom contributed a comprehensive and detailed evidence questionnaire to the call for evidence for the 2010 review.