Sea. From the floor, Fred Roots (former Director of PCSP) commented that although planning where there are no obvious opportunities for support can be a depressing exercise, the process of planning can itself prove to be useful. Art Grantz (USGS) began by stressing that the US had never managed to mount programs in the Arctic that had been as successful in terms of size and productivity as CESAR and LOREX. For tectonic targets there were a large number of areas to aim at, particularly between the ridges. In terms of exploration methods, he would like to see the advent of deep reflection seismic and more seismic profiling where it could be towed from ships. US and Russian ships, and perhaps the new Canadian Icebreaker, should be able to offer increased opportunities for profiling and bottom sampling. Greater coverage of aeromagnetic surveys was urgently needed (Canada has recently completed a new survey in the Beaufort Sea) and in the future, airborne gravity might offer a tool for both gravity and bathymetry. He felt that the Ice Island should not only have a basic program but a well-organized visitor program for national and international teams that might wish to come in for a short period to solve particular problems. Alan Judge (EPB) felt that detailed studies such as CESAR still lacked the regional context, broader data sets are always needed to interpret local studies. The Ice Island may not achieve this and may not provide the scientific stimulus of expeditions such as CESAR. Nevertheless the drilling problem should perhaps be addressed as a priority and funded through the Federal Government's Unsolicited Proposal program. Among targets for new initiative expeditions, he included the basins between the Alpha and Lomonosov Ridges, the western part of the Alpha Ridge and the Nansen-Gakkel Ridge system and stressed the need for paleoclimatic data. Jack Sweeney (PGC) agreed that drilling should be attempted. He also pointed out that the neo-tectonics of the Arctic must be looked at, in particular, detailed seismicity which would determine which parts were now active. The long-term evolution of the Canadian Arctic Margin had implications for the Arctic Basin and should not be neglected.

In discussion from the floor, it was established as unlikely that ODP drilling would be attempted in the Arctic Basin. It was also suggested that satellite altimetry for bathymetry had promise and emphasized that whatever is attempted, navigation remains a major hurdle for Arctic operations. Fred Roots stressed that Arctic programs have to be "sold" both nationally and internationally and urged scientists to go out and promote their ideas through international Arctic Committees. In a final comment, Larry Sobczak pleaded for continuing efforts to try and release the confidential and "strategic" geophysical data which undoubtedly exist over the Arctic Basin.

For this observer, the workshop showed clearly that the Alpha Ridge is most likely to be tectonically and geologically comparable with the oceanic plateaus of the Pacific Ocean or with "hot-spot" related structures such as Iceland. These tend to be the least understood of oceanic features and it is hardly surprising that the small data sets available for the Arctic have proved so difficult to interpret. The lack of regional data plus the lower latitude bias of most map projections make the synthesis of Arctic Basin tectonics a continually elusive exercise. Barriers to Arctic work are physical, economic and political. They are formidable and any progress has to be supported on at least the national, and probably international, level. For Canada, the new Ice Island and a political awareness of Canadian sovereignty in the North, provide opportunities which the geoscience community cannot afford to ignore.

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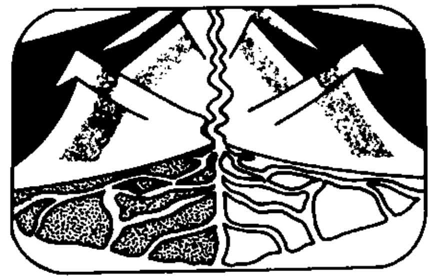

International Symposium on Foreland Basins

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Syn- to post-orogenic sediments in continental foreland basins (molasse) have been studied intensively for many years because they contain significant hydrocarbon and coal reserves, and provide a detailed record of the tectonic events which created the orogen supplying the sediments. As a result, the International Symposium on Foreland Basins, which was held in Fribourg, Switzerland, from 2-4 September, 1985, attracted considerable interest, with over 200 participants from 21 countries. This important meeting, which was sponsored jointly by the International Association of Sedimentologists and the Society of Economic Paleontologists and Mineralogists, consisted of 43 oral presentations, supplemented by 40 poster displays. As might be expected from the sponsoring organizations, sedimentary geologists predominated, although there were a few geophysicists and structural geologists present.

The first half-day of the symposium was devoted to general presentations on the broader geophysical, structural, sedimentological, and hydrocarbon aspects of foreland basins. The following 2½ days consisted of case studies (including several significant reinterpretations), subdivided into sessions on the basis of geography and age: Paleozoic and Archean Foreland Basins (13 contributions); Asian and Australasian Foreland Basins (3); Himalayas and Siwaliks (7); Pyrenées and Ebro Basin, Spain (7); Swiss Alps and Molasse Basin (7); French Alps and Apennines (11); the Rocky Mountains (13); and 10 miscellaneous presentations describing examples from Chile and Argentina, Svalbard, the Persian Gulf, the Greek Hellenides, Turkey, and southern Spain. Over 80% of the contributions were on Mesozoic and Cenozoic fold belts, but the examples ranged in age from the Archean Fig Tree and Moodies Groups of South Africa (Eriksson and Harris, Virginia Polytechnic, Blacksburg, VA) to the presently-active foreland basins of western Taiwan (Covey, Exxon, Houston), the Timor-Tanimbar Trough (Audley-Charles, University College, London, UK), the

Himalayas (various authors), the Adriatic Sea (Ori *et al.*, U. di Bologna, Italy) and the Persian Gulf (Purser, U. de Paris-Sud, France). In addition to 2 oral contributions (Thompson, GSC, Vancouver; Cant, Alberta Research Council) and 2 poster displays (Jerzykiewicz, GSC, Calgary; Gregor *et al.*, Petrel Consultants, Calgary) on the Alberta foreland basin, Canadian examples consisted of the Proterozoic of the Slave Province (Grotzinger, Virginia Polytechnic, Blacksburg, VA; Hoffman and Tirrul, GSC, Ottawa), and the Middle Ordovician, Taconic foreland basin in Quebec (Hiscott, Memorial U. and Pickering, Leicester U., UK). However, Canadian participation and attendance (8 registants only) was surprisingly low in light of the large number of foreland basins (possibly as many as 10) present in Canada.

The various contributions provided an excellent survey of current thinking on foreland basins, and gave an outstanding overview of basins which I had known previously only from disjointed, site- or unit-specific studies (e.g., the Appenine submarine fan literature). Indeed, the larger-scale basin-analysis approach of many of the presentations, which was possible because of improved chronostratigraphic correlations using key beds and depositional sequences, was one of the highlights of the conference for me. Given the diversity of approaches and the absence of a widely-accepted conceptual framework for foreland basin development, it is not surprising, perhaps, that no single idea or theme unified the meeting, except for a desire to link sedimentation and tectonics in the broadest sense; indeed, it was refreshing to see the importance of eustatic sea level fluctuations played down for a change.

In the opening talk, Karner (Durham U., UK) examined the geophysical controls on foreland basin development. He pointed out that in many instances (e.g., the Alps and North American Cordillera) the thrust sheet load can account for only part of the foreland depression, and that a "hidden", subcrustal load is needed to create the observed subsidence. He also discussed (with Kusznir, Liverpool U., UK) how basin width and depth are dependent on lithosphere rheology and, thus, on its temperature and thermal age. Such considerations appear to provide a first-order explanation for the significant differences in scale between the very wide (up to 500 km) Canadian Cordilleran and Himalayan foreland basins (both on cold, stiff Precambrian crust) and the much narrower Alpine trough (70 km) which rests on younger, warmer and more flexible Hercynian basement, and for the lack, in the Rockies, of the early, deep-water phase which characterizes most other foreland basins.

This geophysical approach to foreland basins, although far from new, appeared to excite considerable interest, particularly with regard to the possibility of predicting the amount and timing of subsidence in the basin, and of uplift and lateral migration of the forebulge. (Several people were interested in the role that the forebulge might play in generating unconformities and localizing offshore sand ridges.) In fact, Karner seemed to acquire an almost god-like mystique, as evidenced by the frequency with which he was called on to "resolve" outstanding questions. It became rapidly obvious, though, that the geophysical models are not yet sufficiently detailed to answer the types of questions posed by sedimentologists.

From the structural perspective, Vann (BP, London) described how the deformation styles of the southern Canadian Rockies and Alps differed due to their contrasting lithologies; the southern Canadian Rockies have predominantly bedding-parallel thrusts because of the thick, competent carbonates, whereas the Alps have more folding due to a greater proportion of incompetent fine clastics (and also greater ductility caused by the thicker nappe sequence; Ramsay, Geologisches Institut, Zurich). Within the Canadian Rockies themselves, Thompson pointed out that a similar change in structural style occurs as the amount of shale in the Lower Paleozoic section increases northward; and further south in the Colorado Plateau area, yet another structural style exists, because low-angle subduction and "underpinning" by oceanic crust promoted basement-involved, rather than thin-skinned, tectonics (Cross, Colorado School of Mines). Such along-strike differences in the nature of deformation may exist in other mountain belts as well, and should be reflected in the sedimentary record, but little information is available on this at present.

Vann (and Graham, BP, London) also considered thrust geometry and sequence in greater detail, paying particular attention to out-of-sequence thrusts because of their sedimentological importance, which was reinforced by several Alpine and Pyrenéean workers. In addition, Vann emphasized that tectonic inversion of pre-existing rift structures is important during the compressional stage of foreland development, but its influence on the sedimentary record was not discussed.

In a paper which set the tone for many of the contributions, Elliott (Liverpool U., UK) summarized how foreland basin sediments are often intimately involved with the ongoing deformation. (Excellent examples of this can be found in the Excursion Guidebook which describes trips to the Swiss Molasse Basin (Homewood *et al.*), French Alps (Elliott *et al.*), Swiss Alps (Ramsay *et al.*), and Appenines (Ricci Lucchi and Ori)). In areas such as the French Alps (Apps, Evans, and Davies, Liverpool U., UK), Pyrenées (Atkinson, Shell, The Netherlands and Elliott), Appenines (Ricci Lucchi, U. di Bologna, Italy; Ori *et al.*), and Himalyas (Coward, Imperial College, London) a significant portion of the foreland basin fill was deposited on moving thrust sheets, in "thrust-top" or "piggy-back" basins. In such settings, structurally-produced topographic lows, such as the lateral ramps or terminations of thrust sheets, commonly localize the fluvial or turbidity current systems feeding the basins, creating point sediment sources which control the isopach and facies distributions. Emergent thrust tips, or folds growing over buried thrust tips, can create confined basins or divert rivers and turbidity currents into an along-strike orientation, so that regular proximal-to-distal facies patterns do not develop; indeed, Ricci Lucchi stated that such confinement of turbidity current in the Appenines prevented the development of "normal" submarine fans (quotation marks his)! Only when the basin is full may sediment spill over into more distal, sediment-starved areas, causing the depocentre to migrate outward in a step-like fashion even though the overall shortening is continuous. In addition, major episodes of thrust movement can create localized syn-tectonic unconformities, or generate discrete, upward-coarsening sequences in response to increased sediment supply. Such sequences were the only evidence of tectonic influence reported from the Alberta foreland basin (Cant; Jerzkiewicz); indeed, the strong, direct interplay between structure and sedimentation reported from other basins came as a surprise to many of the Canadians present. The reason for the apparent difference in southern Alberta is not clear, although it might be related to the differences in structural style discussed above.

Despite the various ways in which structure influences sedimentation, the ability to recognize periods of greater tectonic activity from the sediments is questionable, at least on the small scale. Most of the participants supported the old adage that thick, coarse clastics equate with tectonic activity, whereas fine-grained, condensed sequences represent tectonic quiescence. However, in one detailed study combining structural and sedimentary observations, Apps *et al.* came to essentially the opposite conclusion. Several of the factors which might break the direct link between tectonism and sediment accumulation are: out-of-sequence thrusts which alter the locations of source areas and depocentres; compartmentalization of the basin by structural highs so that adjacent areas respond differently to the same tectonic event; and the possibility that tectonic activity may not always create the subaerial relief needed to produce large quantities of sediment. In a large-scale example of this latter point, Covey proposed that the early deep-water phase in most foreland basins occurs because the actively-growing orogen is largely subaqueous and cannot supply great volumes of sediment; consequently, subsidence outpaces deposition. Only later, when the orogen becomes emergent, does sediment production increase sufficiently to cause filling of the basin. From this point on, however, subsidence, coupled with the escape of sediment from the ends of the basin, equals the sediment production rate so that shallow marine and fluvial deposits accumulate in a "steady-state" situation. (Labaume and Seguret (USTL, Montpellier, France) suggested, alternatively, that the shallowing in the Pyrenées is due to tectonic uplift associated with crustal shortening.)

Two subsidiary topics which recurred throughout the meeting were the rates of the processes involved in foreland basin development, as highlighted by the detailed paleomagnetic work of N.M. Johnson and others (Dartmouth College, Hanover, NH), and the petrography of the sediments. A survey of the cited rate data shows that sediment accumulation rates averaged over several millions of years are remarkably consistent between basins, varying only between 0.12-0.8 mm yr^{-1}. By contrast, the long-term rates of crustal shortening (~1 cm yr^{-1}) and lateral migration of depocentres or facies boundaries (3-30 mm yr^{-1}) are more variable and nearly always an order of magnitude or more higher. Long-term averages such as these, although providing general constraints on the tectonic processes, are of limited use in detailed studies, however, due to the unsteady nature of the processes in the shorter term, as evidenced by out-of-sequence thrusts, differential sedimentation rates in response to topographic/structural barriers, and the step-like migration of depocentres.

Sediment petrography did not figure prominently in its own right, although it did appear in a supporting role in many of the presentations. In a survey of foreland basins, Schwab (Washington and Lee U., Lexington, VA) concluded that, while quartz-rich, feldspar-poor sandstones of craton derivation are common in the early stages of foreland development, most of the basin fill contains less quartz and abundant rock fragments derived from the rising orogen; the bulk chemical composition of these sediments closely resembles that of "ancient eugeoclinal assemblages", and contrasts markedly with those of aulacogens, fore-arc basins, and trench-abyssal plains. On the general level, Schwab was unable to detect a systematic mineralogical evolutions through the life of a foreland basin, a finding which contrasts with the results of the more detailed, area-specific studies.

Although there may have been little that was revolutionary, this was a stimulating and enlightening meeting for this outsider to foreland basin studies. Some of the insiders expressed frustration that no major advance or concensus was achieved on the outstanding problems of foreland basin development, but this hope seemed somewhat premature, given the incomplete integration of the geophysical, structural, and sedimentological perspectives. Additional studies of modern foreland basins are also needed to clarify relationships which are obscure in ancient fold belts. Certainly, the meeting demonstrated clearly that the most exciting advances will come when the disciplines work together.

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