# CONCLUDING REMARKS

R. E. POLLOCK

Indiana University Department of Physics and IUCF, Bloomington IN 47405 U.S.A.

In its fourteen meetings, this cyclotron conference series has met at number of pleasant locations, but perhaps has never been favored with a site of such dramatic geographical impact. Capetown and its surroundings cannot but impress the visitor with the beauty of its confluence of beaches and mountains, vineyards and parklands It is a place steeped in history, at once a modern city and a reminder of the past.

The impact of this place on a first-time visitor (such as this author) stimulates reflection about our scientific enterprise and its relationship to the civilization in which it is embedded. The southern tip of Africa, like the eastern coast of North America, had its early explorers, men like Vasco da Gama and Columbus, whose names are familiar to every schoolchild. We admire their spirit and celebrate their accomplishments, although in the contemporary style, we may take issue with some of their methods. Science also has its early explorers, and in the cyclotron field the name of Ernest Lawrence is celebrated for his discovery of the tip of the large continent of circular accelerators.

The motivation of explorers is not always congruent with their accomplishments. One is reminded that Columbus set out to establish a new path to a known destination, so as to gain for his financial backers a competitive foothold in the spice trade. He did not expect to find a new world.

Scientific exploration is likewise filled with examples of truly significant discoveries that have emerged from a quite disparate motivation. In fact one of the strongest arguments for continued financing of scientific work is the prospect that the future of civilization may depend on new worlds not yet foreseen, but perhaps to be uncovered by our persistent curiosity.

The early explorers often have had very little to guide them. Maps may be incomplete, misleading or wrong (the earth is not flat). Even the stars of the southern hemisphere must have been a confusing navigational aid to one raised north of the equator. Shipwrecks on treacherous coastlines, such as are graphically still evident on the rocky coast of the Cape Peninsula are reminders that exploration is fraught with risk. Scientific exploration also carries its risks and dangers. The young practitioner, in particular, must carefully weigh the consequences of failure in pursuing new and exploratory directions against the potential benefits, while realizing that the greatest of discoveries await the most intrepid of explorers.

After exploration comes settlement and colonization. Both the Cape region of South Africa, the eastern seaboard of America and the St Laurence region of Canada attracted European settlers in the seventeenth century. To move into, and build upon the areas opened by the early explorations required a willingness to tolerate dislocation and a commitment to persevere through the daily hardship of a pioneering existence. We see this phase of the scientific enterprise in many papers at this conference, as cyclotron technology and its related skills is transferred to new laboratories, and as more advanced techniques become the foundation for upgraded capabilities of existing laboratories.

Be very clear that the scientific enterprise has explorers and settlers working in parallel. The scientific landscape has a fractal geometry. Two persons starting from nearby points can find themselves traversing very divergent paths, one perhaps to founder on the rocky shoals of harsh reality, while the other emerges into a fertile region which will attract a fresh generation of settlers.

In the development of civilization, the settlement phase seems to lead inevitably to conflict. As the work of the settlers first exposes and then increases the value of a new area, there will be a struggle for control of the newfound wealth. At different times, for example, each of the three settlement regions mentioned above found themselves in conflict with the power structure, represented at that time by the British Empire. The French settlers along the St. Laurence River lost a battle on the Plains of Abraham near Quebec City in the eighteenth century and have been sometimes reluctant partners in the Commonwealth ever since. (A referendum for Quebec independence was scheduled for later in the month of the conference.) Later in that century, the American colonists broke their political ties with Great Britain while retaining a cultural association ("divided by a common language") that continues to the present day. The Dutch settlers of the Cape had their dispute with England in the South African or Boer War at the turn of our present century, becoming a part of the Empire for nearly sixty years, and an independent republic thereafter.

The scientific enterprise leads to conflicts of a somewhat different character. As the value of a new area becomes evident, there can be pitched battles for control of the intellectual capital, and for the power and wealth that can become available by their exploitation. For example, the economic potential can lead to patent disputes and industrial secrecy. Perceived military value can lead to classification or export controls with sad examples of progress slowed by these impediments to free exchange of ideas. The economic burden of ambitious development of a new area can become so large that political decisions disrupt funding patterns, with projects cancelled and careers destroyed (the Waxahachie syndrome). Sometimes the side effects of a new technology, as in the case of nuclear power generation, can create intense opposition delaying or blocking rational utilization. Settlers and colonists generate disruptive side effects, and sometimes the political response to such activities as the destruction of tropical rainforests, or the depleting of populations of whales or salmon or ozone molecules, can be too late to limit the damage.

The struggles for control of a developing region, whether from within or without, can have tragic human costs. The American civil war is a particularly savage example, involving not only a dispute over political independence of a region, but a moral issue over exploitation of a displaced African population. Sometimes from such conflicts great leadership emerges, and Abraham Lincoln is revered for holding his country together through a most difficult period. At this conference we were privileged to be addressed by Mr. Nelson Mandela, the South African President, and a highly respected leader who must bring his country through a similar period of difficult readjustment. Our hopes for his success go with him.

When exploration and development lead to a stable environment, family life may flourish. In the cyclotron community, we recognize several families of machines, based on their design characteristics. The flat field cyclotron, for which Lawrence was the explorer and his students and colleagues the early settlers, held sway in the 1930's and 40's. Conflicting needs for a negative radial gradient for focussing and a positive gradient for relativity limited this family to beam velocities below about 0.15 c.

The synchrocyclotron family, which uses phase stability and frequency modulation to overcome this velocity limit, played a critical role in the subatomic physics of the 1950's raising protons to energies of 0.1 to 1 GeV. Meson physics became established with these beams. MacMillan and Veksler were the phase stability explorers of this area, and its settlers were geographically widespread, from Berkeley to Leningrad and beyond.

The sector-focussed family counts among its explorers Thomas for the edge-focussing concept and Richardson for early experimental studies. The settlers of this domain were the founders of this conference series in the late 1950's, and many of the cyclotrons used for research in the 1960's were of this family. Industrial examples abound, making this still the largest family in our field. Most of these machines operate in the 10-100 MeV region. Continuous beam production gives these machines much higher average current capabilities than the synchrocyclotrons.

In the 1970's a family of ring (separated magnet) cyclotrons was founded. Explorers of the non-spiralled, straight sector variety were M. Gordon (theory) and M. Rickey (experiment). The delegates to this conference were treated to a tour of a modern member of this family at the National Accelerator Center at Faure, a few kilometers east of the conference site. About a dozen large machines of this type are operating at other sites. Members of this family have the design benefit of easy beam extraction owing to the lower average field and to the ample space available for low-stored-energy, high-voltage acceleration cavities.

Spiral-sectored ring cyclotrons retain vertical focussing to higher energies. The meson factories in Canada and Switzerland are examples of this configuration, along with a new member of the family in Osaka. Reports at the conference show the progress being made in delivery of higher intensity (polarized and unpolarized) beams, and in better beam quality.

A newer family with first examples operating in the 1980's employs superconducting coils to create magnetic field higher in strength than the saturation limit of iron poles. Henry Blosser, a recognized explorer of this new territory along with the Chalk River group, gave a summary of the history and characteristics of this family in the preceding talk at this meeting. The strength of the design lies in the relatively higher energy available from a magnet of modest size. Difficulties include the more intricate mechanical design due to space constraints, the high power into the rf systems, the high electric field of both the rf and electrostatic extraction elements, and the cost and operational issues for the cryogenic systems which maintain the low coil temperature. Several members of this family are in use for heavy ion research, and two of these reported commissioning successes at this conference. Interestingly, both of these most recent family members were assembled at one location, then moved geographically to a new site for research operation.

We also heard about the startup tests of a novel separated-turn design which has separate cryogenic coils on each turn and also multiple superconducting rf cavities. The explorer of this new ground is U. Trinks (München) and settlement of this intriguing continent lies in the future.

We saw other examples of exploratory work that could lead to new families of machines. A 235 MeV radiotherapy cyclotron has an unusual ellipsoidal pole gap which gives a rapid field falloff at large radius to ease extraction. Yves Jongen is the explorer of this therapy machine concept, and the benefit to humanity of having more appropriate therapy beams available is the "search for the spice islands" that drives this development. Designs of machines optimized for isotope separation and identification were presented. Also design studies for several new projects which endeavor to combine superconducting coils with separated sectors were presented, indicating that this technically rather challenging marriage of the two families may be fruitful.

In addition to the several cyclotron families in evidence at this conference, one must note the continuing representation of related technologies. Electron cyclotron resonance (ECR) ion sources have become the input device of choice for many heavy ion cyclotrons, and the continuing rapid progress in this area of development was evident at the meeting. The performance boundaries of the ECR concept are becoming clearer with time as the underlying physics is studied, and appear not yet to have been reached.

A second cyclotron-related technology in continuing evidence in this conference series is the family of cooled storage rings, several of which have cyclotrons for beam injection. Explorers of the cooling concepts were antiproton collider enthusiasts at Novosibirsk and Geneva. That the settlers of this territory may be found at cyclotron laboratories is not because the technology is the same, but rather because the motivation for beam quality improvement is appreciated by the cyclotron community. We heard that future upgrade plans at RIKEN, Lanzhou, Dubna and Indiana all include such rings.

A topic of continuing interest that does not appear to fit the explorer, settler, family metaphor is the role of collective potentials ("space charge forces") in limiting intensity and extraction efficiency. Continuous progress, both at PSI where the extracted beam power is approaching a megawatt, and in the smaller machines for isotope production, is evident. However it should be cautioned that the somewhat closed (self referential) society of cyclotron enthusiasts may not yet fully appreciate the insight to be gained from a parallel activity in the "non-neutral plasma" community in the study of dense trapped ion clouds, often under conditions where the collective potential effects are far larger than for present-day accelerator beams. The trapped ion cloud is after all just a very intense beam which has been brought to rest in the laboratory frame where it may be subjected to detailed scrutiny. The explorers of this physics have seen glimpses[1] of relevant concepts and phenomena that might well merit a bit of tourism or even settlement by those who seek to understand intensity limits at a more fundamental level. To push the family metaphor, there is a danger of in-breeding if we fail to pay attention to the beauties uncovered in neighboring tribes.

A similar remark might be made about the subject of beam tails or haloes. In seeking to understand how the halo can mysteriously reappear after being scraped off during transport in periodically-focussing channels, Jameson and co-workers[2] have been exploring the coupling between individual particle motion and the time dependent collective potential of the beam as a whole. The periodic envelope modulation gives rise to an exchange of energy so that emittance for an individual particle is no longer a conserved quantity. Such particles may find themselves within the beam body and inaccessible for scraping part of the time and part of a halo at other times where they can create losses and activation problems. Being more aware of this mechanism should help designers of future intense beam accelerators.

What do we learn from trying to relate the evolution of science to the explorer/settler/family-life metaphor? First we note that the linear progression model applied with variable success to the history of civilization is of limited use for our scientific culture, because in science all the historical phases operate in parallel. Fumbling exploratory work in one subfield progresses in parallel with the settlement activity in another, as successful explorations bring more settlers to exploit the advances, while the stable family phase is in evidence in yet another subfield, as its settled areas are optimized for maximum benefit.

Second we note that we scientists are not operating apart from our society as a whole. We must remain sensitive to context: financial support does respond to political priorities, and not one of us is entitled to a free ride. We need to explain the relevance of unrestricted exploration of the boundaries of our Cape Peninsula of knowledge projecting into the rough seas of ignorance.

Finally we note that civilization is usually tied to history and geography in inextricable fashion. But the research community has developed a new paradigm which may serve as a model for future improvements to society as a whole. Science jumps geographical and political boundaries with marvellous ease. At international conferences such as the one just concluded in Capetown, scientists mingle happily and effectively, crossing the boundaries of culture and language. Part of this ease arises from a shared value system: we each recognize work of quality by others in the field and respect accomplishments independent of their origin. Boundaries once crossed by scientific interest can only with difficulty be made impervious again. The communications network being built upon a foundation established in science (remember the World Wide Web originated in CERN) is overwhelming political attempts to restrict information flow, and promises to spread the free interchange of ideas beyond its scientific beginnings.

As for the cyclotron community itself, the vital signs are strong. More than 150 attendees from 26 countries participated in the 14$^{th}$ International Cyclotron Conference, showing the continuing interest in the field, and an unwillingness to allow geographical distance to limit participation. The 182 scientific contributions as talks or posters show some indication of the level of activity. The diversity of reports is striking, ranging from the commissioning of new facilities, to performance upgrades of existing facilities, to construction starts on future facilities, to design studies for ambitious new projects, to design concepts for totally new directions. All this activity is a strong indicator of the health of the field.

Speaking for the conference delegates, I would like to offer warm thanks to the organizers of the Capetown conference for selecting a stimulating program and for providing comfortable arrangements, diverting excursions, mostly fine weather, and memorable hospitality.

The international committee concerned with the planning of this conference series has agreed that a 15$^{th}$ conference should take place in about three years time and has accepted the offer of the French laboratory GANIL near Caen to serve as host and organizer for the next meeting. We hope to see you there.

## References

1. See bibliography compiled by J. Fajans in "Non-Neutral Plasma Physics II", AIP Conf. Proc. **331** 271 (1995).
2. R. Jameson, Proc IEEE Particle Accel Conf (1993), p 3926, IEEE 93 CH3279-7.