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IMPACT OF THE NORTH AMERICAN DATUM (NAD83) REDEFINITION ON THE PETROLEUM INDUSTRY

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Abstract

In the near future the NAD83 geodetic datum will supersede the currently used and long-established NAD27 datum. This change is considered desirable because of greater accuracy requirements from, primarily, the resource exploration and development industry and for spatially referenced geographic information systems. Also, the change will give compatibility with coordinates derived from the Global Positioning System (GPS). It will cause the geographical coordinates of points to change by as much as 120 metres and their UTM grid coordinates to change by around 200 metres. These changes will clearly have a large impact on the use of any data which are coordinate-dependent, for example, lease information, well location and attributes, pipeline location and attributes, seismic location and section data, geological maps, reservoir attributes and topographical data.

The definition and computations for NAD83 have taken over fifteen years of intense discussions, mathematical and software development, implementation and data analysis. The petroleum industry has patiently sat on the sidelines and watched from afar in anticipation of the day when the conversion would begin. When the datum was first announced, extensive computer data bases were not in existence and most people envisaged that the transformation would take place over several years with no great impact. However, the industry did not sit still on other fronts and there has been a proliferation of coordinate-dependent data bases both on land and offshore.

The objective of this paper is to inform the members of the petroleum industry community of the impact of this redefinition on them as users of these data. The paper first briefly describes what the changes are and why they have occurred. Then discussed is the effect of these changes for the conventional land areas of western Canada and for the Canada Lands both offshore and onshore. These two categories are further broken down into the exploration, development (legal and engineering) and data base areas. Some recommendations and suggestions are given to enable a smooth implementation of NAD83.

Introduction

A discussion on NAD83 should begin with an overview of what a coordinate really describes. It should be made clear, as illustrated in Table 1, that a point may have several latitudes and longitudes, each with a different reference frame. This problem has become more common as exploration has proceeded offshore and moved into extremely remote areas where there are few, if any, identifiable features.

The oil and gas industry is dependent on a technically complex combination of electronic, computer, geodetic, atmospheric and survey-related sciences to position its seismic, geological, geotechnical, engineering and drilling components of exploration. Millions of dollars can be invested in a drilling location, from preliminary seismic to final exploratory drilling. The successful prospect areas may then generate hundreds of millions of dollars in revenue and, hopefully, profit if the oil and gas fields are brought into production. The requirement for accurate and reliable positioning and an understanding of the meaning of quoted coordinates is therefore a critical element to these operations. Industry, especially with respect to the offshore areas, has responded to this challenge with a wealth of technologically sophisticated positioning hardware, ranging from underwater acoustics to satellite receivers. Yet, with all the new equipment and procedures developed, the seismic vessel or drilling platform may still be 200 metres from its proposed location if there has been an error in the basic understanding of coordinate systems and datums.

There are different types of coordinate systems used in positioning. Terrestrial coordinate systems are used for positioning earth-located points, celestial coordinate systems are used for positioning stars and orbital coordinate systems are used for positioning satellites. Each type of coordinate system has a unique relationship to the Earth and its movements. Of principal concern to the petroleum industry in the areas of exploration and development is the relationships between terrestrial and orbital coordinate systems.

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The type of terrestrial coordinate system utilized throughout the world is one of the numerous ellipsoid-based reference frames. The position of a point is expressed as a geodetic latitude, longitude and ellipsoidal height. The ellipsoid on which this system is based is usually positioned in the Earth so that its origin is close to the Earth's centre of mass, or geocentre. The size as well as the position and orientation of the reference ellipsoid within the Earth defines the datum being used. A local datum and its associated ellipsoid, such as NAD27, is usually chosen by a country so that it best fits the geoid in that country. The geoid is a surface of constant gravitational potential which is approximately represented by mean sea level over the Earth. Thus, a local datum which may be appropriate for one country may not be appropriate for another. In this case, a new ellipsoid with a different shape, size, orientation and origin may be adopted.

The positions of the TRANSIT and NAVSTAR satellites which we commonly use for navigation are expressed in an orbital coordinate system, based on a satellite datum, which is then converted to a terrestrial system. A satellite datum has its origin placed at the Earth's geocentre and is defined by the system in which the satellite ephemeris is given. NAD83 has been chosen such that it is very close to the satellite datum.

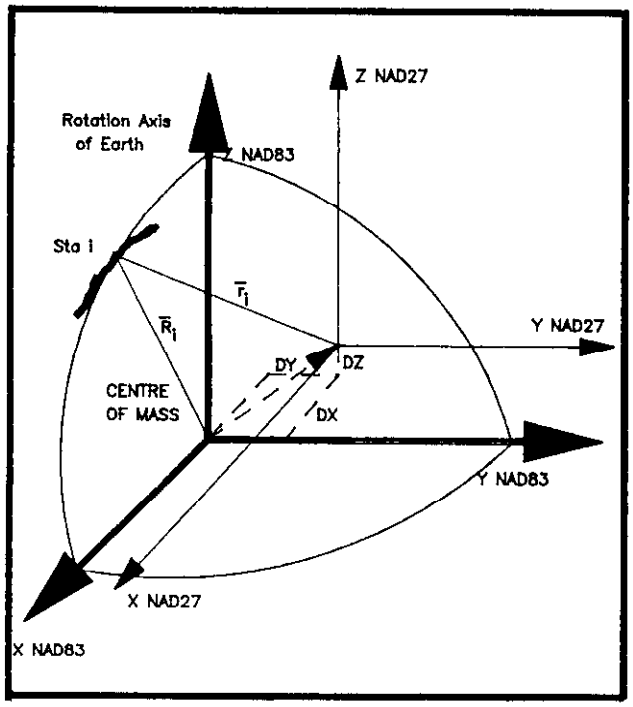

Fig. 1. Comparison between NAD27 and NAD83.

The confusion arising from coordinate frames of reference is probably best illustrated by Figure 1, which depicts two global coordinate frames differing only by translations. Table 1 is given to show the reader the approximate magnitude of change between NAD27 and NAD83 in various parts of Canada. MAY76 refers to an intermediate adjustment carried out prior to NAD83 and for which coordinates are sometimes provided on request; MAY76 has the same ellipsoid parameters as NAD27. The grid coordinates are based on the appropriate Universal Traverse Mercator (UTM) zone.

EASTERN CANADA STATION LAUZON

Datum	Latitude	Longitude	Northing	Easting
NAD27	46 48 52.6049	71 09 27.5643	5186604.974	335393.735
MAY76	46 48 52.5741	71 09 27.8790	5186604.206	335387.042
NAD83	46 48 52.6848	71 09 25.8675	5186824.830	335434.813

WESTERN CANADA STATION RESERVOIR

Datum	Latitude	Longitude	Northing	Easting
NAD27	53 29 11.1300	113 26 33.3448	5928943.770	337933.375
MAY76	53 29 11.5095	113 26 32.8128	5928955.160	337943.581
NAD83	53 29 11.3681	113 26 36.9486	5929170.263	337872.891

NORTHERN CANADA STATION TUK

Datum	Latitude	Longitude	Northing	Easting
NAD27	69 26 15.1770	133 01 52.6480	7704215.845	577161.544
MAY76	69 26 14.7741	133 01 51.3795	7704203.814	577175.751
NAD83	69 26 15.0765	133 02 02.5376	7704386.817	577050.644

Table 1. Magnitude of change between NAD27 and NAD83 in various parts of Canada. The grid coordinates are based on the appropriate UTM zone.

Table 1 shows that errors of hundreds of metres are possible if the datum is not clear. For precise geodetic work, one would, of course, use rigorous transformations to relate the frames involving translations, rotations and scale parameters. However, without knowing the coordinate frame upon which coordinates are based, the user can introduce totally nonreconcilable differences into the data base. Figure 2 shows the anticipated difference, in metres, in geographical coordinate positions between NAD27 and NAD83 at this time.

This paper attempts to outline the effects of the redefinition of a coordinate frame on the oil industry operations. Many points will be raised, some having simple solutions and others having more complex solutions. Every corporation, big or small, must address the problem in a fashion which best suits its needs.

Conventional Land Areas

Seismic surveys

In the past, little concern was given to the accuracy of positioning of geophysical surveys. Seismic lines were surveyed using stadia; coordinates were calculated, hand-plotted, submitted to the client (oil company) and traced onto their shotpoint base maps. As survey practices improved, so did the quality of seismic surveys. The improvement can be attributed to a number of factors:

1. the use of Electronic Distance Measuring Devices (EDM);
2. additional survey control [Doppler, Inertial Survey Systems (ISS), Global Positioning System (GPS)];
3. computerized surveying processing;

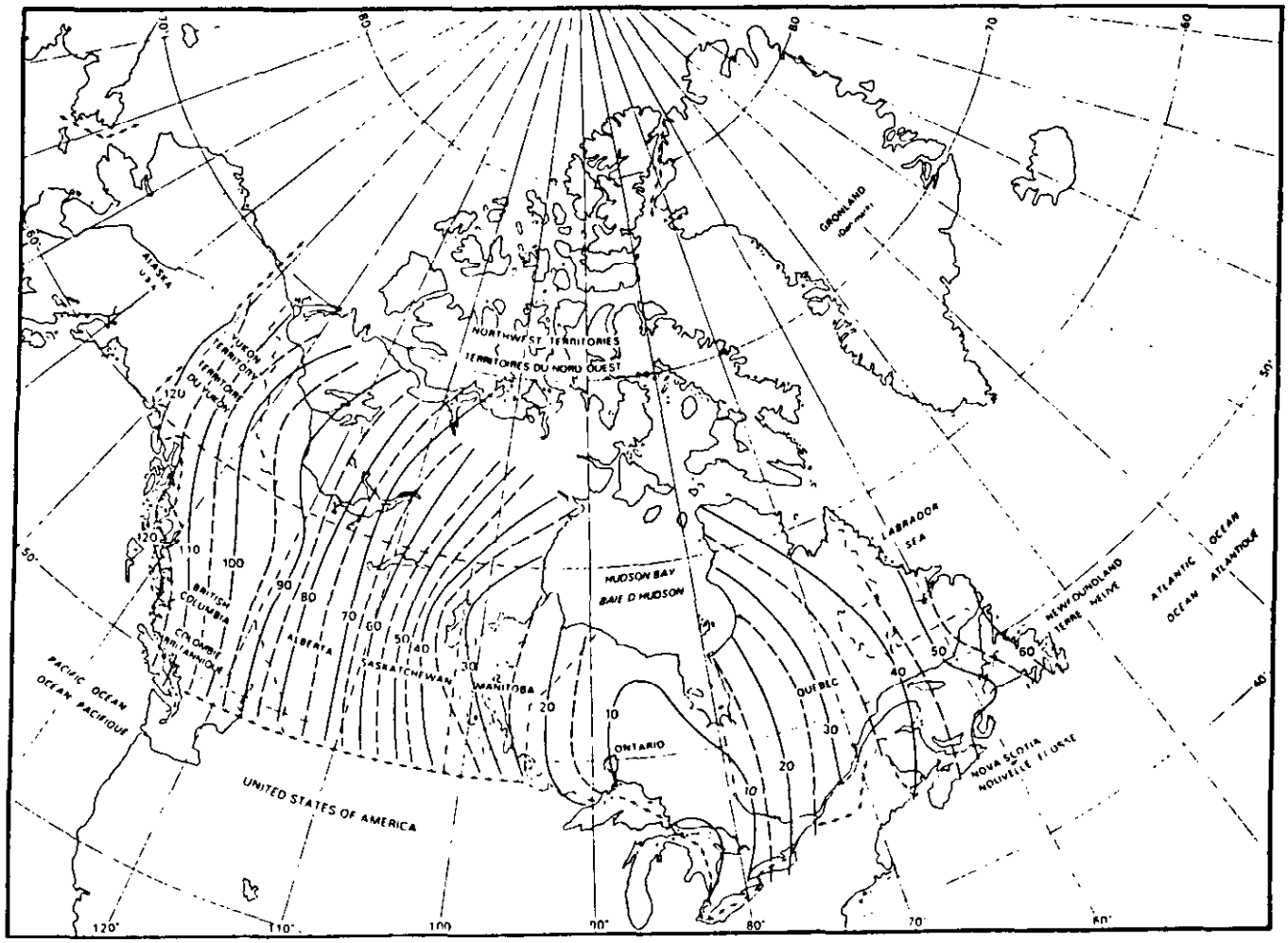

Fig. 2. Anticipated differences between NAD27 and NAD83 (metres). (Source unknown.)

4. updated township files in Alberta and Saskatchewan;
5. and in the future, NAD83.

No matter what the coordinate definition, seismic surveys in western Canada will always be related to physical evidence in the field. In Alberta, Saskatchewan and the Peace River Block of British Columbia, this will be the Township System, while in northeastern British Columbia the surveys will be referenced to primary, secondary or other control and tied to the National Topographic Series (NTS) map-sheet system. The coordinates of shotpoints and datums may change but the physical location on the ground will never move. This physical location is identified with an affixed shotpoint tag at a source point for 2-D seismic and at both source and receiver points for 3-D seismic surveys.

When a well site is drilled on a 2-D seismic location, the coordinates given are cross-referenced to physical evidence in the field and located accordingly. For 3-D surveys, the coordinates given for a drilling location are for a subsurface point and cannot be physically identified on the ground. Since these coordinates are the only indicator for the location, it is of utmost importance that the reference datum be known and consistent with the surface coordinate datum.

Currently, all coordinates are related to NAD27 datum. The changeover to NAD83 will not change the present field techniques but will have a large impact on computer processing of survey data and shotpoint data bases. This will be addressed further in the section on data bases.

In conclusion, the following are key points that need to be recognized in handling geophysical surveys:

1. The reference datum is currently NAD27 and in the near future will be NAD83.
2. In Alberta, which Alberta Township System (ATS) coordinate file is being used for generating township coordinates?
3. In Alberta, it is preferable that the Alberta Survey Control (ASC) monuments be tied into the Third Dominion Lands Survey (DLS) System. (The same holds true for Saskatchewan.)
4. In British Columbia be sure to know the datum for triangulation stations and well sites.
5. When the geophysical surveys (both 2-D and 3-D) are computer-processed and put into a shotpoint data base, the computed coordinates should be compatible with the existing shotpoint coordinates in the base and the map grid on which the shotpoints are plotted.

In other words, be *consistent*.

Development

The following discussion will briefly describe the methodology used in the positioning of development structures in each of the provinces and the effect that the datum redefinition may have on them.

The term "development" refers to any activities carried out on the land surface for the purpose of drilling, producing, processing and transporting hydrocarbons.

Well sites: Alberta and Saskatchewan — Once the geoscientists have determined the optimum location to drill a well, it is up to the "legal" surveyor to position and mark the well centre with reference to the Township System. The well may be located either: (a) at predetermined coordinate values; or (b) at or near a shotpoint *tag* of a seismically controlled exploration program, as described in the previous section. The well is surveyed to meet the petroleum operator's objective as well as various criteria set by government regulations.

It is a government requirement that the position of the well centre and the *posts* planted to demarcate the well site lease boundaries be known relative to the position of the northeast corner of section thirty-three on the baseline in the range in which the survey lies. Another requirement is to know the position of the well relative to the nearest section boundaries in the areas designated as "surveyed territory" and to the theoretical section boundaries in the areas designated as "unsurveyed territory".

In surveyed territory, survey ties are made to the *monuments* at the section/quarter-section corners or survey traverse *posts* relative to them. *Posts* of registered legal surveys intrinsically tied to the Township System are also used as well site control. In unsurveyed territory, in many cases, the requirements are met by making ties to section monumentation or traverse *points* of existing surveys which relate to the nearest Baseline *monument* (i.e., NE corner, Sec. 33). An approved ASC monument may also be used. In Alberta, such surveys are approved by the Director of Surveys as well site traverse plans.

Prior to drilling a well, the petroleum operator must apply for a well license. The government requirements that have to be met with respect to well site position are more specifically outlined below.

In Alberta, Part 2, Section 2.020 (3) of the Energy Resources Conservation Board Oil and Gas Conservation Act and Regulations states the following:

(3) An application under this section shall be accompanied by a suitable plan showing:

(a) "the location of the well, tied by bearings and distances to an "*approved monument*" as defined in the Well Location Survey Regulations or to a "*regulation post*" established by the provisions of the Well Location Survey Regulations,"

(b) "the relation of the well location to the boundaries of the quarter section shown by the coordinates from the two boundaries of the quarter section that are also boundaries of the section, assuming a 20 metre wide road allowance, and by calculated distances to the interior boundaries of the quarter section;"

In Saskatchewan, in Part IV, Section 10 of the Oil and Gas Conservation Regulations, 1985, it is stated that:

(a) a plan of lands:

(iv) "showing the exact location of the proposed well site in relation to:

(a) the boundaries of the section; within the same drainage unit.

(vi) "having all measurements and distances tied to:

(a) a surveyed monument or evidence of a surveyed monument in a surveyed area; or

(b) a surveyed base line or some prominent topographical feature acceptable to the department in an unsurveyed area;"

(vii) "having an entry in its legend stating the true East/West and North/South coordinates of the well site from its initial reference section corner *monument* used in the survey. . ."

Well sites: northeastern British Columbia — In British Columbia the government requires that the well site and survey be positioned in reference to the Township System if it is located in the Peace River Block, otherwise in relation to the National Topographic Series map-sheet system used in defining the permit and lease "grid" system set up under the British Columbia Petroleum and Natural Gas Act. In most instances a surveyor may refer to the well centre location relative to a *monument* of the Township System or to a government triangulation *station*.

A few of the government requirements that are needed prior to obtaining a well authorization (permission to drill) are specified in Division (20.) of the Ministry of Energy, Mines and Petroleum Resources Drilling and Production Regulations:

20.08 The final survey shall show:

(a) "the commencement and the closing point to be a *monument or monuments* of the township system in the Peace River Block, or the township or other cadastral system in the Lower Fraser Valley, a Government triangulation *station or stations*, *monuments* which have been established under this section, or Provincial boundary or highway right-of-way *monuments* which have been coordinated on geodetic datum and are acceptable to the Surveyor-General. . . ."

(c) "the survey relationship of the well position to the nearest corner of the spacing area in which it is positioned;"

(d) "the latitude and longitude of the well position;"

(j) ". . .The origin of coordinates shall be an adjoining whole degree of latitude and an odd numbered meridian of longitude . . ."

Pipelines and other structures — In the western provinces there is a government requirement that legal dispositions or leases be obtained for such structures as a pipeline in a right-of-way or easement, a production facility or a processing plant. A legal survey and plan is usually

required to have the operator's right registered in a Land Titles Office. To be a legal survey there is a requirement that legal survey *posts* be planted on the boundaries of such areas. As was the case with well sites, these development structures are physical entities affixed on or below the land surface and are referenced positionally to the survey fabric through ties of the legal survey monumentation process.

Effect of NAD redefinition

We have italicized the terms "monument", "post", "station", "point" and "tag" to indicate that these are physical reference markers on the land surface. They have attributes which are tangible and visible and they are usually permanent in nature. Thus, one can visually see the location of a structure or the indicators of a boundary line on the land surface. Due to these attributes, the NAD redefinition will not, in most cases, have any impact on the structures on the land surface. On land the physical markers, *not* the coordinate values, will govern the property boundaries.

When NAD83 is implemented, new geographical and mapping coordinate values will be assigned to the monuments of the Township System, triangulation stations and other survey control markers. This will subsequently necessitate the assigning of new coordinate values to:

(1) existing well sites;
(2) pipeline right-of-ways;
(3) production facilities such as gas plants, batteries and satellites and their lease boundaries;
(4) refineries, etc.; and
(5) the associated traverse surveys of all of the aforementioned.

Even though structures and boundaries will not be affected on the ground, petroleum companies must be aware that they must accommodate the impending coordinate changes if they have coordinate data bases. This is discussed later. Overall, the petroleum companies need not be concerned about the possibility of their property boundaries shifting and, therefore, losing land holdings or other assets to adjacent operators, the Crown or private individuals. However, they should be cognizant of some of the problems that could arise prior to, during and after the transition phase of NAD83 interpretation. A hypothetical case is cited below.

As mentioned earlier, seismic shotpoint tags are physically identified by the surveyor and then surveyed relative to a control reference marker. A well is then drilled at the flagged shotpoint. However, this procedure is not followed when predetermined coordinate values are used in positioning the drill-site location, in which case the surveyor stakes the proposed well at the coordinate values in reference to the existing survey fabric. In most circumstances there is no physical evidence that can be used to confirm the required location. The only confirmation is to drill the well and determine if the target is met! When only coordinate values are used for spotting a well, potential problems could occur. The following describes a scenario where the "old" and "new" datums are inadvertently used in positioning a drill-site location.

A 3-D seismic program was performed prior to the NAD83 implementation. The shotpoint positional locations were gathered, processed and generated using the NAD27 datum. A shotpoint was selected for a potential prospect but for some reason the drilling of the location was deferred. Some time later, after NAD83 had been adopted, it was decided that the well be drilled.

The shotpoint information and coordinate values, still based on NAD27, were issued to the surveyors. Due to much activity in the area the shotpoint tags could not be found. The issued coordinates were used in spotting the well centre. This normally would have been acceptable except, in this particular instance, the well was surveyed relative to the control monumentation now having NAD83 values. By referring back to Table 1 or Figure 2, the magnitude of error may be seen.

This type of situation means that, effectively, the well could be drilled and miss the downhole objective by 100 to 200 metres. This could be very critical if the target was a small pinnacle reef or if the well was being directionally drilled. Such an occurrence could be very costly and detrimental to a company which thought it was drilling a low-risk well.

Thus, again it is stressed that the petroleum companies and their contractors need to be aware which datum is being used.

FRONTIER

This section is paraphrased from the paper "Offshore Legal Surveys – Datums and Charts" by Harold Jones and David Gray (1986).

Offshore considerations

In 1969 it was recognized that the survey regulations designed for land use would require modifications in order to provide both accurate and reliable survey techniques and surveyed positions offshore. The Department of Energy, Mines and Resources in cooperation with six other departments and the Canadian Petroleum Association convened a workshop in 1970 to study the technical and regulatory problems and the perceived need for control monuments in the offshore. Canadian offshore survey procedures were profoundly influenced through the recommendations and basic findings of the workshop. Some of the specific recommendations were:

— Permanent monumentation of surveys at sea is impractical and unnecessary except where resource development provides a permanent bottom-mounted platform.
— The protection provided by a legal survey is required only where a valuable resource has been discovered, but the requirements for a legal survey should be set out as a yardstick to govern exploratory or other surveys.
— The positioning report for an exploratory well should

include adequate information of the survey system and clearly identify the shore-based control used, so that the position could be reoccupied.

— To ensure competency of Canada Land Surveyors offshore, the schedule of examinations must include examinations in geodesy and offshore positioning. Hydrographic surveyors must be brought into the legal survey profession.

Offshore legal surveys

Legal surveys, regulated by the Surveyor General, are performed under legal requirements and pertain to the establishment of boundaries of legal rights in land, including land under water. Only Canada Land Surveyors may perform surveys of legal rights on Canadian land. In onshore and offshore areas there are many other types of surveyors, such as hydrographers, who survey bottom topography, tidal limits and currents, and geophysical and geological surveyors. These groups are not governed by the Canada Land Surveyors (CLS) Act or regulated by the Surveyor General. However, their surveys may be the basis on which legal boundaries are defined; once a boundary becomes a boundary of legal right it becomes the subject of legal surveys under instruction of the Surveyor General.

The legal survey of a structure such as a production platform is analogous to a mortgage certificate where the boundaries are not monumented; it is essentially a description of a position relative to the boundaries.

Oil and gas surveys

The Canada Oil and Gas Grid defines, in terms of latitude and longitude, the limits of rights for oil and gas exploration and development. The Grid Area, which is the largest division, is a square with sides of about 20 km extending 10 minutes in latitude. Each Grid Area is subdivided into sections about 2 km square and sections are subdivided into units about 500 m square. Exploratory rights are commonly granted for groups of full or half Grid Areas while development rights are commonly granted for groups of sections. The need to regulate a definitive survey comes into effect, according to the workshop, when a resource has been clearly defined in its extent and is ready for production. At this time there would be bottom-mounted structures in the offshore that could serve as sites for local monumentation and which might act as witness monuments to surrounding boundaries.

Regulations were set up to protect the holder of rights by designating the first legal survey of a production well in a Grid Area to be definitive. These regulations established that all boundaries of and within the Grid Area are defined by the theoretical distances from the well, based on the coordinates established by that first legal survey. Similarly, the position of any subsequently surveyed well in that Grid Area is determined by using the first well as control. Thus, the well becomes a sort of witness monument to all boundaries in the area coincident with the Grid Area. Subsequent first legal surveys in an adjacent Grid Area similarly establish its position, but any overlap as a result of inaccuracy or blunder is deleted from the subsequently established Grid Area. Provision is made for disposing of rights to gores which will similarly develop.

The 1985 workshop on oil and gas surveys

Workshop development — Following the 1970 workshop, the "Surveys" and "Monuments" sections of the Canada Oil and Gas Land Regulations were revised. The Surveyor General drew up an appendix to his Manual of Instructions for offshore legal surveys (for development wells) and Specifications for Positioning Reports for Offshore Exploratory Wells were published jointly by the Department of Indian Affairs and Northern Development and the Department of Energy, Mines and Resources and republished by the Canada Oil and Gas Lands Administration (COGLA). In 1985 a Government Industry Workshop consisting of 27 delegates and invited speakers met for 3 days to consider recent developments and make recommendations.

Adoption of NAD83 — The major purpose of the 1985 workshop was to consider a proposal to adopt NAD83 as a framework for oil and gas rights and to recommend appropriate changes to the regulations. The adoption of the virtually distortionless NAD83 would eliminate problems such as the ill-definitions in progressing offshore using NAD27.

Adoption of theoretical boundaries — An associated proposal was to adopt NAD83 theoretical boundaries rather than accepting the first legal survey as definitive for its Grid Area. With the present possibility of providing even first-order accuracy to stable platforms in the offshore by satellite translocation techniques and the possibility of making many independent checks against blunders, it is feasible to adopt theoretical boundaries. In view of the anticipated drilling of several offshore development wells in the near future such boundaries would avoid the difficulty of administering and describing dozens, perhaps hundreds, of small gores and deficiencies in Grid Areas.

The adoption of NAD83 theoretical boundaries is feasible due to the present possibility of providing first-order accuracy to stable platforms in the offshore by satellite translocation techniques and the possibility of making a number of independent checks against blunders.

Preservation of NAD27 – defined rights — In the Canadian offshore, the adoption of NAD83 in place of NAD27 would arbitrarily shift boundaries of oil and gas rights by 60 to 120 metres. The workshop recommended changes to the Canada Oil and Gas Land Regulations which would provide for the adoption of NAD83 as the theoretical grid (i.e., the same coordinates would define the grid which would put the grid in a different position) subject to the opportunity for holders of rights to maintain NAD27 boundaries at Significant Discovery areas. Exploratory rights already granted would continue to be explicitly bounded by the appropriate theoretical grid. This would happen upon a declaration by the Surveyor General when the NAD83 adjustment process has progressed to the

stage where ample NAD83 control is available. In preparation for revising the survey regulations, COGLA has investigated the 91 Significant Discovery areas so far declared. In 21 of these, the boundary of an Exploration Agreement (EA) crosses the Significant Discovery. There are also a few cases where, in the same EA, ownership proportions change for different Sections within a Significant Discovery. Figure 3 shows one of the more complicated situations. COGLA expects to have revised regulations in force once all jurisdictional matters are resolved.

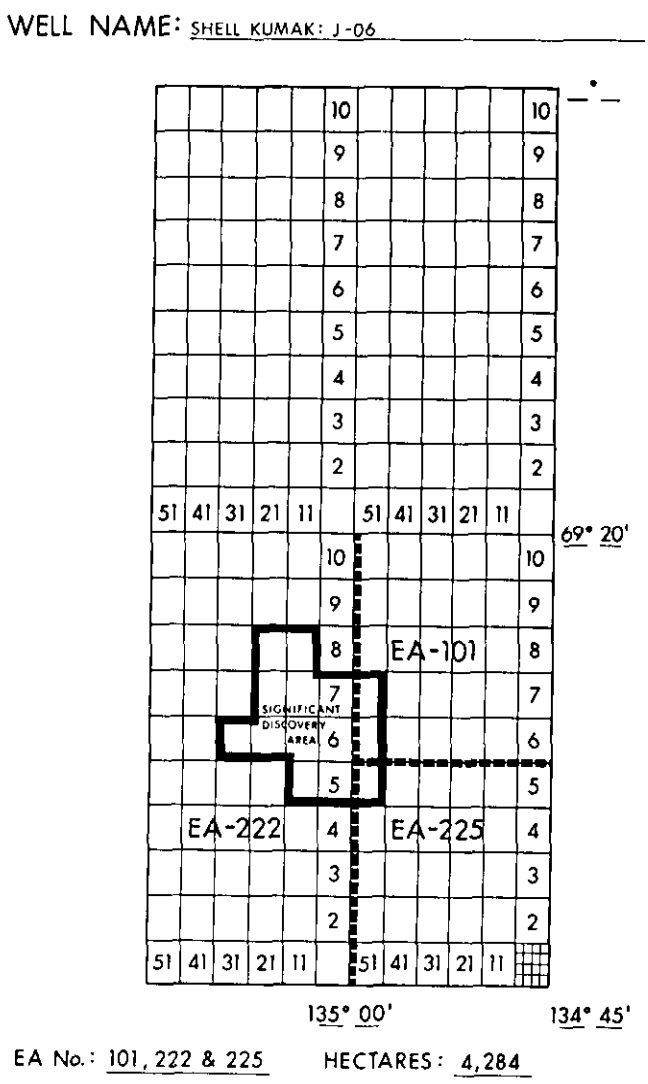

Fig. 3. Example where the boundary of an Exploration Agreement (EA) crosses a Significant Discovery Area.

Workshop recommendations — The workshop made several other recommendations concerning associated matters that it studied related to NAD83:

— That the Dominion Geodesist, after consulting with the Surveyor General, will be designated the final authority on the relationship between datums.

— A computer program termed ESTPM involving some 16,000 parameters has been written and debugged and will be available with its documentation for general distribution. The program and its documentation will be registered in the Canada Lands Surveys Records as the official transformation program that defines the relationship between NAD27 and NAD83 (Blais, 1979).

— A meeting should be convened with representatives from the Department of External Affairs, Geodetic Survey, Legal Survey, International Boundary Commission and Canadian Hydrographic Service to agree on appropriate NAD83 coordinates for the turning points of the Gulf of Maine International Boundary. However, before further international meetings are held, informal discussions and negotiations between the Dominion Geodesist and the Director of the United States National Geodetic Survey are necessary.

Data Bases

Updating of coordinate data is being performed on two fronts in the near future, namely the NAD27 to NAD83 transformation and the continuous updating of the Township files to which legal and seismic work is referenced. Both of these updates will have enormous effects on the integrity of coordinate data bases because of the magnitude of the coordinate changes, and they should consequently be given equal emphasis.

The primary condition to be satisfied during this conversion is that the homogeneity and integrity of *all* data must be maintained. We must consequently not only consider those data bases where coordinate data is a "primary" data item (e.g., seismic lines, wells) but also those cases where coordinate data might be considered "secondary" (e.g., interpreted contours and faults, topographical data, Land Related Information System (LRIS) data bases, maps stored as graphic files, SEG-Y formatted seismic tapes). Some of these are areas where the surveyor is often not traditionally concerned, and yet for the purposes of this conversion a high level of survey involvement must be maintained. In achieving this, the recent popularity of personal computers and workstations, which take data from main corporate data bases for specific applications and which frequently lead to a proliferation of coordinate data outside the well-controlled master data bases, will be a major complication. All such data must be sought out and converted. For large organizations this will be the most difficult and time-consuming task, one that should not be underestimated.

The administrative changes which should be made in coordinate handling are similar for both the Township and NAD changes.

Township files

In general, work in surveyed territory will be tied to the Township System, either directly by locating pins, or indirectly by, for example, tieing to well sites which have previously been surveyed to pins. In Alberta, for example, the Township System is far from homogeneous and large relative errors of up to 100 metres are known to be present between markers. The provincial government first published a theoretical ATS file in 1977 and have updated this at various intervals (ref., ATS Version 3.0 description, Feb. 1988). Private companies, recognizing errors in the file, have also made their own corrections to it, resulting in a proliferation of ATS files with different coordinates.

The effect of this on the field surveyor is very important. When making a tie between two markers which are genuinely in error, the problem is obvious and appropriate action can be taken which may result in the updating of the coordinates of one marker on the ATS file. At a later date, on a survey by another company, this corrected marker may be used with "old" coordinates, and if a tie is not performed to a "correct" marker its erroneous coordinates will not be detected and a relative error between the first and second survey will result. With the errors which exist in the system this may be very significant. As a consequence, any data observed and computed relative to a Township System and then transferred to geographical or grid coordinates will be dependent on the use of a particular Township file. This file may not be compatible with that used on another system or by another company which purchases the data and, therefore, the data will be corrupted.

NAD27 to NAD83 transformation

All coordinate data in both digital and analogue form will require converting from NAD27 to NAD83. The problems to be overcome in this conversion can be split broadly into those which are technical and those which are administrative. Assuming that all new data will be collected and loaded in NAD83 coordinates, the former is primarily a short-term problem involving deciding how to perform the conversion of existing data. However, the latter is a long-term problem requiring continuous coordination between organizations and monitoring of data status.

Whether positioning data are held in geographical coordinates, grid coordinates or as local offsets to township section corners, the transformation will have an effect on the stored data or the processing functions. The first two will require the application of coordinate shifts, whereas for the latter, the local offsets themselves will remain unchanged but the Township grid file, relative to which all the local offsets are made, will require conversion. The Township file will, of course, be converted from NAD27 to NAD83 as well as being routinely updated as previously discussed.

With regard to the method to be used for the conversion, Canadian Geodetic Survey has not yet made any recommendations on how it should be done or what regional distortions exist. One would anticipate, however, that, for practical reasons, the custodians of large data bases will have to make an approximate transformation according to the attained and required accuracy of their data. This will, of course, lead to the administrative problems involved in deciding which data require a rigorous transformation (e.g., control-point data) or which can be approximated. The latter would lead to edge-matching problems if a non-continuous approximation were used, for example, simple latitude and longitude shifts to blocks of data. It is a principle concern of the federal and provincial survey and mapping agencies that this transformation be performed correctly.

During the changeover period there will be many areas where problems will occur due to missing or wrongly interpreted information or where previously simple tasks suddenly become complex. For example:

— maps will be purchased or retrieved which are incompatible;

— overlays of new data based on NAD83 will not be usable with existing maps on NAD27;

— merging of data sets on the two datums will not be possible before the NAD27 data has been transformed to NAD83;

— standard map-sheet layouts based on geographical or grid coordinate limits will have slightly different contents of ground features or data;

— all software will have to be changed to handle the new geodetic parameters for geographical to grid and datum to datum conversions;

— definitive coordinate lists previously in use will have to be replaced, as will all geodetic station descriptions (or at least the coordinate data on them will need rigorous converting — this also applies to the Township upgrading);

— coordinates previously written on seismic tape headers will no longer be valid. These currently do not include datum information for later reference. This also applies to the Township upgrading.

The logistic implications of the above decision should not be underestimated. Rasbury-Merrick and Taggart (1987) estimated that U.S. National Geodetic Survey's least-squares transformation program LEFTI running on a standard VAX 11/750 would take 11 minutes CPU time and 16 minutes elapsed time to convert 5000 points. Extrapolating this to the many millions of points existing on seismic and topographic data bases and adding on I/O costs (which would become very significant for data records where the coordinate was just one attribute in a very large record) indicates that this conversion will be computer-intensive and a complex logistic task. Simpler solutions can be defined, but then the maintenance of data integrity will become an important issue.

Administrative aspects of Township and Datum changes

Aside from the technical problem of how to convert the existing data, a bigger problem will be the increased administrative effort required to closely monitor the data status. The technology exists to overcome all of the problems associated with the transformations providing the data, whether it be in digital, map or written forms, are adequately documented with the geodetic datum on which it is based. This will require two main processes which should be implemented immediately:

i) All digital coordinate data no matter where it is stored (e.g., survey, seismic, topographic data bases, SEG-Y headers) should in some way be annotated with the correct datum information. This can be achieved, for example, by putting the information on separate files, on the file headers, or in every record, but this information must always be included when data are traded or sold; otherwise the data will potentially lose a great deal of value.

ii) all maps should be annotated clearly with the datum information, preferably automatically when plotting the map. This is already being done by all the national and provincial survey organizations in North America.

Of course, having implemented i) there must also be a mechanism by which this information is provided when data are exchanged or sold. This will require the adoption of appropriate standard exchange formats.

Conclusions

1. The changing of the reference datum will have an impact on all oil industry users no matter what their size. Data bases which are based on latitude, longitude and height, northing and easting, or Township System coordinates must be closely examined for future compatibility. All survey data requested by an oil industry user must now and in the future have the reference datum (NAD27, NAD83, Township System version) clearly stated. This has been implied in the past but will no longer be valid. The industry should establish a definitive survey-data exchange format similar to that used by some offshore operators. This should definitely include datum information and, optionally, control stations and their coordinates used in the survey. The opportunity could also be taken to include other raw and quality control data essential to the validation of the survey. This would then ensure that trade data (which often are exchanged without any raw survey data) would not create severe confusion in the future.
2. Conversion programs relating NAD27 to NAD83 should be standardized as much as possible to ensure compatibility.
3. Future data bases should anticipate the new datum and thus allow for fast and, hopefully, painless conversion. As has been stated many times, "Nothing is constant but change," and this is true for any reference datum that has its parameters based on a physical data set which is constantly being refined. The oil industry must allow and plan for that change in a technically prudent manner which begins with a knowledge of the coordinate frames themselves.

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