VIRTUAL CARBONATE THIN SECTION USING PDF: NEW METHOD FOR INTERACTIVE VISUALIZATION AND ARCHIVING

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ABSTRACT: As personal computers increase in processing power and storage capacity, it has become feasible to digitize an entire carbonate thin section area, and to digitally manipulate and archive such digital image files for research collaborations and teaching purposes. This paper describes procedures for creating and authoring virtual carbonate thin sections in PDF format with a 35-mm film scanner, bitmap image editing software, and a Windows or Macintosh personal computer running Adobe Acrobat. A petrographic thin section is scanned at a maximum optical resolution of the 35-mm film scanner and the scanned image is used as a base layer of the PDF file. A digital microscope camera is used to capture high magnification photomicrographs that can be linked to the base layer to highlight specific features of the thin section. Collapsible text boxes are used for text annotation and various graphical annotation marks are used to indicate 'hot areas' that are linked to other photomicrographs for interactive viewing of the image. This method is highly flexible and platform independent, and can be beneficially used in various ways such as a note taking tool for routine petrographic work, creation of virtual samples for classroom use where the students have limited access time to the reference sample, long-distance research collaborations between scientists, and ultimately, creation of teaching- and research-grade visual carbonate petrography databases.

INTRODUCTION

High-resolution electronic imaging devices are rapidly displacing traditional film-based photomicrography. The advantages of digital imaging compared to conventional photography are multifold: it can be stored on a variety of media, transmitted over computer networks, and will not degrade over time as long as the storage media remains intact. In addition, digital images can be used for presentation, archiving (Newman et al. 1995), making 35-mm slides (Dartnell and Gardner 1993), as resources for web pages, and for automated quantification of rock properties (e.g., Ehrlich et al. 1984; Ruzyla 1986; Ehrlich et al. 1991; Coskun and Wardlaw 1993; Ferm et al. 1993; White et al. 1998; De Keyser 1999; Prince and Ehrlich 2000).

The image of a whole thin section area is generally used as a 'map' for optical petrography, scanning electron microscopy, electron microprobe analysis (Miller 1988), interpretation of fabric development (Halsor and Wolfe 1992; White et al. 1998; De Keyser 1999), microfacies analysis of limestone (Flügel 1982), archiving, and visual aid for geoscience education. The traditional method of photographing the whole thin section is to prepare a negative print (Miller 1988), or a negative reversal print (Haneef 1993) with a photographic enlarger, or to prepare photo-mosaic with low power (1x or 2x) objective lens and a 35-mm film camera mounted on a polarizing microscope. However, these methods require considerable amounts of time, experience, and cost to obtain satisfactory results.

It has been demonstrated that a petrographic thin section or an acetate peel of carbonate rock can be directly scanned and saved as a digital image file by a 35-mm film scanner (De Keyser 1999). The main advantages of this method compared to conventional photographic print methods are: instant results, cost-effectiveness, and rapid production of publication quality images (De Keyser 1999). With the continuing increase of personal computer processing power, hard disk drive storage capacity, and widespread use of low-cost removable storage systems such as recordable CDs and DVDs, it is increasingly feasible to digitize the whole carbonate thin section area, digitally manipulate and archive resulting files, and distribute these files on CD- and DVD-ROM discs and transmit them via LAN and the Internet for research collaborations and teaching purposes. This paper describes procedures for creating and authoring the virtual thin section in PDF format by using common "off the shelf" software. This approach potentially provides a cost-effective yet powerful solution for creating user friendly and interactive digital petrography contents that can be used for undergraduate- and graduate-level laboratory exercises, long-distance research collaboration, and ultimately, creation of teaching- and research-grade visual carbonate petrography databases.

EQUIPMENT AND SOFTWARE USED

Images for creating virtual thin sections are acquired in two ways. The image of entire thin section area is acquired by direct scanning of a thin section (or an acetate peel) by a 35-mm film scanner (De Keyser 1999). In our project a Minolta Dimage Scan Multi 35-mm film scanner with maximum optical resolution of 2,820 dpi at 24-bit color depth is used to scan thin sections. A Macintosh G4 personal computer (400 MHz CPU, MacOS 9.1, 1 GB of RAM, 100 GB of hard drive, a CD recorder, a DVD-RAM drive, and a 21-inch monitor) is used to receive and archive acquired images from the film scanner. Selected high-power photomicrographs are captured by a Nikon Digital Camera DXM1200 (maximum resolution of 3,840 by 3,072 pixels at 24-bit color) attached to a Nikon Eclipse E400 Pol polarizing microscope. Acquired digital images are enhanced and manipulated by bitmap image processing software Adobe PhotoShop (version 5.0). Adobe Acrobat (version 5.0) running on a Windows personal computer (1 GHz CPU, Windows XP Professional, 512 MB of RAM, 20 GB of hard drive, a CD recorder, and a 14-inch monitor) is used to convert the acquired images into a virtual thin section file. Overall, this method is not platform-dependent and comparable hardware and software can be used. The main requirements are a 35-mm film scanner, a bitmap image editing software, and a Windows or Macintosh personal computer running Adobe Acrobat.

PROCEDURE

Standard size petrographic thin section (or acetate peel) is scanned at a maximum optical resolution of the 35-mm film scanner (Burns 1997; De Keyser 1999). It takes about a minute to scan a standard size petrographic thin section at 2,820 dpi optical resolution. Each scanned image measures approximately 4,000 by 2,700 pixels and about 31 MB in size. The thin section may be sandwiched with polarizing film to facilitate plane-polarized light and cross-polarized light as needed (De Keyser 1999). A glass cover slip mounted with mineral oil significantly enhances the quality of the scanned image. High-power digital photomicrographs are captured by a digital microscope camera with pixel resolutions between 1,600 x 1,200 to 3,840 x 3,072 pixels and 5.5 MB to 33.8 MB in size, respectively. These acquired image files are cropped as needed, sample number and scale bar are placed, and edited using Adobe PhotoShop for color and sharpness in order to give the image a color that closely resembles the color that can be seen under a microscope. Then the images are saved to a local hard disk drive as lossless Tagged Image Format File (TIFF). These TIFF files can be opened and edited by many similar bitmap-image editing software products on Windows, Macintosh, and Linux personal computers. Images captured by the digital microscope camera are typically re-sized to 1,000 by 800 pixels before incorporation into PDF file. If the photomicrograph needs to be seen in detail, it can be re-sized to about 2,000 by 1,600 pixels.

The archived TIFF image from 35-mm film scanner is used as a base layer of the PDF file. There are several different ways to convert archived TIFF images to PDF file format. The archived TIFF files can be directly opened and converted to a PDF file by Adobe Acrobat using the option of 'Open as Adobe PDF', available under the 'File' menus in Adobe Acrobat: there are five different JPEG compression levels and a lossless ZIP compression option available. Maximum- and high-quality JPEG compression settings resulted in good image quality while providing a much smaller file size than the original TIFF file format (Table 1). Adobe Distiller (version 5.0), a component of Adobe Acrobat, could also be used to convert TIFF files to PDF format. Both the Press Job with 2400 dpi and maximum quality JPEG compression option, and Print Job with 1200 dpi with maximum quality JPEG compression settings produced good results (Table 1). Adobe Distiller can be used for automated batch conversion of TIFF files to PDF format (Padova 2002; Alspach 2002; Sahlin 2002).

Collapsible text boxes (pop-up note) placed on the image are used to facilitate text annotation. Collapsible text boxes can contain information related to the whole sample or, to a specific area of the thin section. Text boxes appear as a note icon (Fig. 1A) until clicked by the user (Fig. 1B). Various graphical annotation marks such as a circle or a square can be used to highlight any region, feature, or constituent grain (Fig. 1A, C). These graphical annotation marks can be linked to pop-up notes and/or high-magnification photomicrographs captured by digital microscope camera (Fig. 1D, E). Additional imported photomicrographs appended to the base layer become additional pages of the PDF file. These photomicrographs can be linked to certain features to provide an interactive navigation option to the user (Fig. 1D, E). Additional components such as an audio file, MPEG movie, and Internet hyperlink can also be embedded in a PDF file as needed. In addition, it is possible to lock the PDF file by setting a password (Adobe Standard Security feature) and to enable various security options such as no content copying or extraction, no printing, and no content changing (Padova 2001; Sahlin 2002).

RESULTS

An example PDF file shown in Figure 1 is composed of a base layer (Fig. 1A) and 9 additional photomicrographs, with 2 of the linked photomicrographs shown in Figure 1D and 1E. The base layer is 4,000 by 2,355 pixels in size and imported to Acrobat using maximum quality JPEG compression option (Table 1). The photomicrographs are re-sized to 1,000 by 800 pixels (approximately 2.3 MB each in size) before incorporation into Acrobat. These files are imported into Acrobat using high-quality JPEG compression and appended to the base layer as additional pages of PDF document. The resultant PDF file size is 6.7 MB. The PDF file can be opened and viewed by the Adobe Acrobat Reader application. The user may view and interact with the PDF file via the standard Acrobat Reader user interface functions such as the zoom tool (Fig. 1C) to experience real-time changes in the magnification of the image. The user may also scroll the image using the hand tool, interact with textual annotation by clicking on the note icon (Fig. 1B), and navigate to the linked photomicrographs by clicking on graphical annotation marks (Fig. 1C, D, E). If the PDF file is not password-protected and the user has the full version of the Adobe Acrobat, it is possible to write and attach additional text annotations to a particular feature of the image.

DISCUSSION

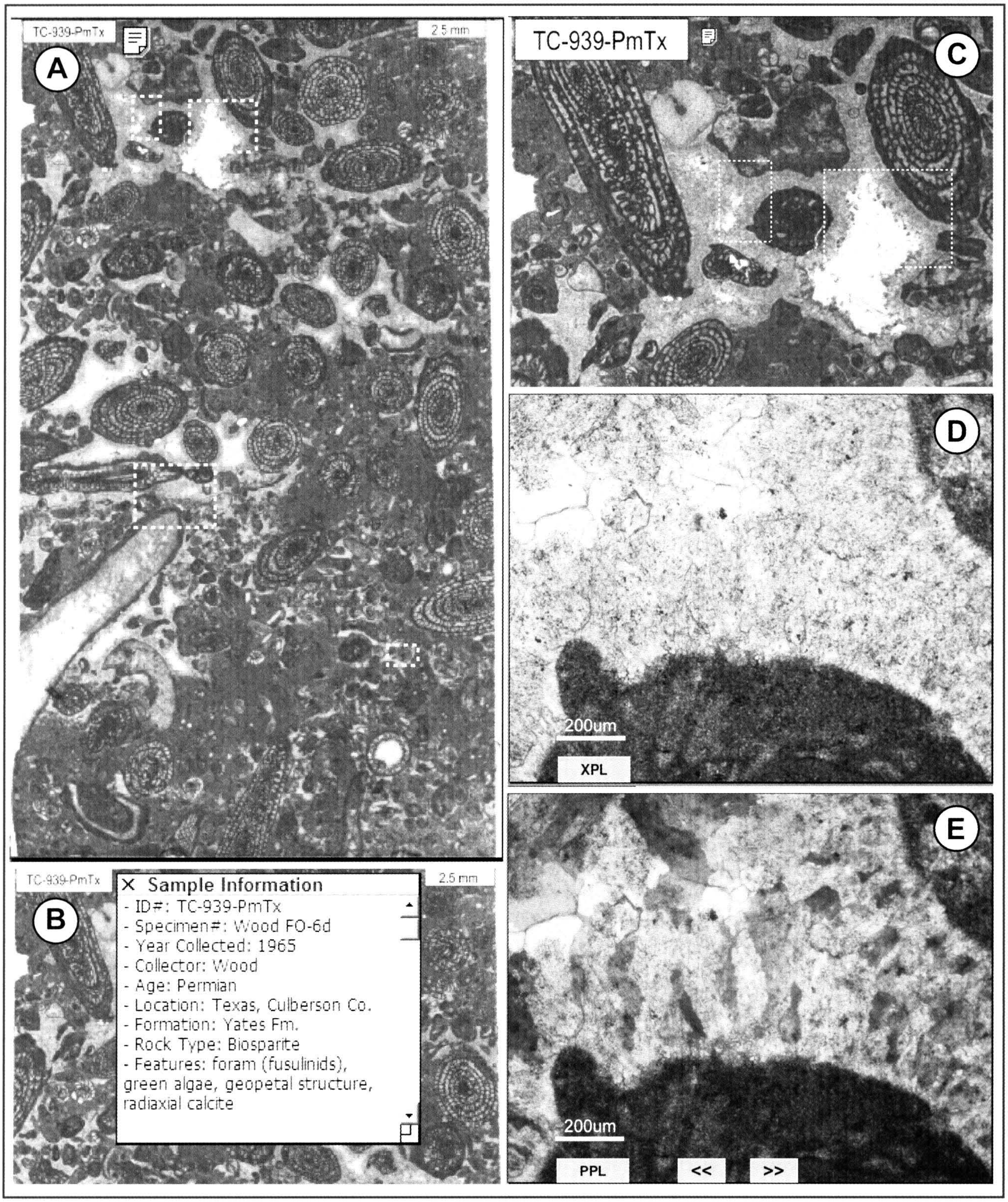
In recent years, digital image archiving and viewing methods similar to those described here have received widespread application in the medical education field in the areas of pathology and histology. Concerns regarding the easily-degrading nature of the samples during the laboratory exercises has prompted these developments (e.g., Trelese

Table 1. File size comparison using different quality level of JPEG compression during conversion of TIFF file into PDF format. File size figures are based on image used for Figure 1A. Maximum- and high-quality JPEG compression under Adobe Acrobat "Open as Adobe PDF" function provided good image quality and high compression ratio (18 to 1 and 22.5 to 1, respectively). Adobe Distiller 2400 dpi Press Job and 1200 dpi Print Job with maximum quality JPEG compression also produced good image quality and small file size.

File type and size (MB) before conversion	Conversion method	File type and size (MB) after conversion	Note
TIFF, 27	(Original TIFF image)	n/a	4000 x 2355 pixels, 24-bit color
TIFF, 27	Adobe Acrobat, ZIP compression	PDF, 23	Lossless compression, file size too big
TIFF, 27	Adobe Acrobat, maximum-quality JPEG compression	PDF, 1.5	Better image quality, 18 to 1 reduction in file size
TIFF, 27	Adobe Acrobat, high-quality JPEG compression	PDF, 1.2	Good image quality, 23 to 1 reduction in file size
TIFF, 27	Adobe Acrobat, medium-quality JPEG compression	PDF, 0.88	Image quality not acceptable
TIFF, 27	Adobe Acrobat, low-quality JPEG compression	PDF, 0.64	Image quality not acceptable
TIFF, 27	Adobe Acrobat, minimum-quality JPEG compression	PDF, 0.5	Image quality not acceptable
TIFF, 27	Adobe Distiller, Press Job (2400 dpi), maximum-quality JPEG compression	PDF, 2.6	Better image quality, 10 to 1 reduction in file size
TIFF, 27	Adobe Distiller, Print Job (1200 dpi), maximum-quality JPEG compression	PDF, 1.3	Good image quality, 21 to 1 reduction in file size
TIFF, 27	Adobe Distiller, Screen Job (600 dpi), maximum-quality JPEG compression	PDF, 0.24	Image quality not acceptable

et al. 2000; Harris et al. 2001; Leong and McGee 2001; Brookes et al. 2001). The need for adequate assessment of very small features such as individual cell cytology or fungal and bacterial identification during routine histological diagnostics requires the use of very high magnification digital images of the entire glass histology slide (Harries et al. 2001; Leong and McGee 2001). This leads to the use of a high-power microscope image of the entire glass slide, because a simple scan of glass slides using 35-mm film scanner (Burns 1997) cannot produce such high-resolution images (Leong and McGee 2001). The task of acquiring high-resolution and high-quality digital images, each up to tens of GB and 100 to 300 MB in size after compression per slide, is done by special software and a hardware package that controls a robotic microscope mechanical stage, digital microscope camera, and automatic image tiling (Harries et al. 2001; Leong and McGee 2001). The processed images are stored on a central server and accessed by end user with client software through the LAN and the Internet (Ferreira et al. 1997; Harries et al. 2001; Leong and McGee 2001).

Unlike medical histology glass slides, scanned carbonate thin sections provide adequate textural and constituent grain type information for routine petrography. This method can be successfully used for imaging carbonate, fine-grained terrigenous mudrock and shale, and some evaporite thin sections. For sandstones, this method appears to be less effective, unless the image is acquired using cross-polarized light in order to make it easier to identify individual sand grain types. Smaller allochems such as cross sectional views of siliceous sponge spicules (diameter approximately 90 μm), can be easily recognized from the scanned image. However, at higher magnification views, the image becomes increasingly pixelated and thus could not match the image quality of photomicrographs captured by a digital microscope camera with a high-power objective lens. Therefore, it is practical to use the scanned image of the whole thin section as a base map and to link high magnification digital photomicrographs to the base layer as needed. Using a film scanner with higher optical resolution in the near future will provide higher quality base maps. A 35-mm film scanner with highest optical resolution currently available offers up to 4,800 dpi resolution, which is capable of providing a larger image file (approximately 6,800 by 4,600 pixels and 80 MB in size per standard petrographic thin section) that could capture finer details of the thin section than the scanner used in this paper.



The advantages of using PDF format are multifold: 1) PDF files are platform-independent and compatible with Windows, Macintosh, Linux, and various Unix computers, 2) the Acrobat Reader program for these computing platforms is available on-line free (http://www.adobe.com/support/downloads/main.html), 3) PDF files can be easily incorporated into a web browser, multimedia authoring environment such as Macromedia Director (Alspach 2002), and also could be coalesced to create a stand-alone interactive CD-ROM (e.g., Thompson 2000; Kerans and Kempter 2002), 4) PDF format is very flexible in terms of content design: the virtual thin section file could consist of a single base layer with multiple text annotations, or, it could be an array of interactive multimedia with

Figure 1. An example of a virtual carbonate thin section made for digital carbonate petrography teaching material. A. Zoom out view of a virtual thin section. Sample identification number on upper left and a scale bar on the upper right side of the image are placed using bitmat image editing software before importing the image into Adobe Acrobat. Note the presence of a note icon next to the sample identification number. Also, note the presence of several dashed rectangles around the image. These 'hot spots' are linked with photomicrographs captured by a digital microscope camera. B. Once the user clicks on the note icon of Figure 1A, the collapsible text box expands and shows the content of the text box. General sample information and features the user needs to learn is displayed. C. Upper left part of the virtual thin section is being viewed. Details of the image can be viewed by using 'Zoom in Tool' to magnify the image and 'Hand Tool' to scroll the image. Clicking on the smaller rectangle in the center of the screen transport the user to linked photomicrograph (Fig. 1D). Field of view is about 10 mm. D. Magnified view of radiaxial calcite and blocky spar cement under plane-polarized light. A small rectangle labeled 'XPL' in the lower left of the image is linked to cross-polarized light view of the same area (Fig. 1E). E. Cross-polarized light view of the same area as Figure 1D. Note that there are three links (buttons) on this image: a button for going back to plane-polarized light view of the image ('PPL'; Fig. 1D), and two buttons linked with additional series of cross-polarized views of the image with 15 degree rotation of stage in both direction in order to demonstrate the characteristic undulose extinction of radiaxial fibrous cements. Once exploring these links, the user could press either 'Go to Previous View' button to backtrack the viewing path or 'First Page' button of the standard Acrobat Reader user interface to go back to the main layer (Fig. 1A).

numerous types of linked photomicrographs (such as CL (cathodoluminescence), BSE (backscattered-electron), and X-ray maps), text and audio annotations, MPEG movies, and internet hyperlinks, 5) when a sufficient number of virtual thin section files are accumulated, these files can be full-text indexed to form a searchable database using Adobe Catalog, a component of Adobe Acrobat, and 6) The resultant PDF file size is manageable (< 10~20 MB per file) for FTP and WWW download as well as CD- and DVD-ROM distribution. Similar functionality described in this paper could also be achieved by using Apple QuickTime VR file format (e.g., Hatch and Leggitt 1998; Trelease et al. 2001; Kerans and Kempter 2002). QuickTime files are compatible with Windows and Macintosh, and the QuickTime player is available free. However, PDF format is chosen for greater compatibility, ease of authoring, and built-in indexing and database search function.

It is reasonable to assert that the value of a thin section or petrographic image resides almost entirely in the information that relates to the specimen. Many types of information lend values to collected rocks: the conceptual framework that led to the collection of the specimen; qualitative and quantitative factual data that describe the specimen at different scales; specific interpretive information pertaining to features contained within the specimen, general interpretive information that places the specimen within a larger framework with other specimens; and value judgments about the specimen (e.g., whether it is 'ordinary', 'typical', 'key', or 'classic'). The significance of virtual thin sections lies in the fact that they permit all these types of value-lending information about a specimen to be closely, unambiguously, and permanently linked to the specimen itself. Another key aspect of virtual thin section is that the amount of recorded information referenced to the specimen is, potentially, both very large and highly flexible. By integrating the processes by which information about rocks is generated, recorded, preserved, and shared, virtual thin sections introduce efficiencies of great magnitude. In virtual thin sections, a single file flexibly serves the purposes of research, archiving, and education.

CONCLUSIONS

The method presented in this paper provides a powerful, adaptable and cost-effective solution for working with digital images of carbonate thin section on personal computer. The method could be used for on-screen viewing, organization, presentation, and archiving of a vast library of carbonate thin sections. This method could be used beneficially in classrooms where the students have limited access time to the reference sample (Sunderman 1993); virtual thin sections can be accessed first to give a general idea regarding the thin section and the subjects to be learned from the sample, then the real thin section can be used to reinforce detailed observations. This method could be used for long-distance research collaboration, each scientist appending their own observations, interpretations, and questions for one another. Routine petrography will benefit greatly from this method because it enables a researcher to link notes directly on top of the digital image that could be viewed, updated, and catalogued on any personal computer. This method can also be used to create interactive digital petrography contents for teaching- and research-grade visual carbonate petrography databases. In addition, this approach can potentially be used in any field dealing with large amounts of visual data, such as seismic interpretation, panoramic outcrop annotation, and remote sensing for image interpretation, interactive visualization, training, and archiving.

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