# A Standard-based Model for the Exchange of 3D Geological Data

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***Abstract*—A wide range of methodologies and software applications have been developed to generate 3-Dimensional (3D) geological model data. One of the main open issues is the exchange of these heterogeneous data from different sources, which influences the sharing and integration of 3D geodata. It is also a necessity to take into consideration the semantics of 3D geological data to enable its full exchange. We proposed a standard based geologic data model (*sGDM*) to offer an xml-based data exchange of 3D geological models. *sGDM* totally reuses the standard of GeoSciML declared by the International Union of Geological Sciences (IUGS) as the core module for defining geological feature objects. Then geological features can be integrated into a geological model within a top-to-down architecture of geological model – feature group – geological feature. The Symbology Encoding (SE) standard from Open Geospatial Consortium (OGC) is utilized and extended by *sGDM* to define 3D visualization parameters of geological features. Besides, *sGDM* has benefited from several other existing standards, such as X3D proposed by Web 3D Consortium, WMS, SLD, CityGML etc. that proposed by OGC. To evaluate the *sGDM*, we also presented a high level prototype architecture for the integrated, xml-based storage and management of 3D geological data. In this architecture, data user and provider softwares exchange information through a communication method using *sGDM*-defined xml streams.**

***Index Terms*—data Exchange, geological model, XML, GeoSciML**

## I. Introduction

Geoscience Information Systems (GIS) provide a means to create and analyze models of real world geological situations based on data. There are large number of 3D geomodelling softwares that provide data models and functionality to represent sophisticated geological situations in three spatial dimensions as geomodels [1-3]. On the other hand, with the recent advances in computer technologies, geological organizations are increasingly dependent on management models for data integration, analysis and web services.

However, a wide range of methodologies and software applications developed to generate data have led to a huge heterogeneity in the logic for interfacing and collecting data. One of the main open issues is the exchange of heterogeneous data from different sources.

In contemporary two-dimensional (2D) GIS, the idea of interoperability of geodata has been promoted in the nineties to overcome the above mentioned heterogeneity problems and allow the sharing and the integration of geospatial data and geospatial resources [4, 5]. The current basis of geospatial data exchange has been worked out by organizations such as the Open GIS Consortium Inc. (OGC), ISO/TC 211, governmental organizations, the geographic information industry and the geographic information academic community. A number of standardized documents such as define the content and the structure of geometric data as well as the semantic description of geospatial data [6-11]. Many applications such as GeoSciML [12] have benefited from these existing standards and successfully used in the exchange of 2D geological data.

Currently, there are no open exchange standards for 3D geological models. Referencing the existing standards, the objective of this work has been the development of a standard-based model for the exchange of spatial and non-spatial properties of 3D geological data.

The reminder of the paper is structured as follows: in Section 2 some related works are reported. In Section 3 the conceptual structure and detailed specification of the proposed data model are presented. Section 4 shows an example application. Finally in Section 5 some concluding remarks and future works are given.

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## II. Related Work

British Geological Survey (BGS) has worked out Geoscience Spatial Framework (GSF) within the project of Digital Geoscience Spatial Model (DGSM) [11]. GSF aims to design, implement and trial a format for holding digital models that: (1) is independent of the originating software, (2) can feed visualization applications (including over the web), (3) will preserve the models as modeling software and proprietary formats are upgraded. BGS has implemented GSF as a 3D geological models' container based on relational database, and made it mainly serve to BSG itself and BSG's partners.

GeoSciML is a general geoscience data exchange standard proposed by the Interoperability Working Group (IWG) under the auspices of the Commission for the Management and Application of Geoscience Information (CGI). GeoSciML is an application of OGC GML, and also has benefited from other existing standards, such as eXploration and Mining Markup Language (XMML), North America Data Model (NADMC1) et al [12]. GeoSciML builds up a conceptual geoscience data model, and maps it to a common interchange format. GeoSciML can work with OGC Web Feature Service (WFS) to enable general geoscience data interoperation in a web-based distributed computation environment.

In another related domain, CityGML has been accepted as a part of OGC GML 3.1.1 standard to act as a public specification for representation and exchange of 3D digital city models [13]. CityGML defines a 5-level LOD structure to describe model details from a regional scale to an in-house scale. As to objects in a city model, CityGML gives encoding format of their semantic, geometry, topology, and appearance properties. And for the appearance property, its 3D visualization parameters, including light, material, and texture, are designed based on X3D standard issued by the Web 3D Consortium.

Both of GeoSciML and CityGML are GML based specifications, in addition to the different domains they focus respectively, they are developed under different principles. GeoSciML focuses on the conceptual geoscience data model, more specifically the data model of representing geologic feature objects. It relies on Web Map Service (WMS), Styled Layer Descriptor (SLD) and other related standards to tell how geologic feature objects integrate together to form a geological map, and how this map can be rendered. GeoSciML itself does not care that the map is 2D or 3D, and how the map looks like. However, the announced WMS, SLD et al standards are only 2D enabled. This restricts GeoSciML's ability for representing 3D geological models. CityGML, by contrast, gives the way to define how feature objects constitute a city model, and how objects show in the model, which means CityGML can independently and fully portray a 3D city model with appearance attributes. However, CityGML cannot represent the conceptual features of geological data.

## III. Standard based Geologic Data Model(*sGDM*)

We presented a data model, called *sGDM*, to exchange 3D geological data based on existing standards. We considered some requirements of *sGDM* for presenting 3D geological data. The main requirements are followed as:

- Ease of use: The exchange data should be easy to write and read.
- Intelligibility: The tags of the exchange data based *sGDM* provide names and abbreviations that clearly indicate their meaning (semantics).
- Extensibility: The data model should support users in specifying new functionality, in order to allow easy adaption to special requirements.

Generally s*GDM* is designed as follows:

First, the data model utilizes GeoSciML as the core module to state the conceptual data model of general geologic domain knowledge and facts. Then, *sGDM* defines types representing geological model and geological feature group, so that geological features can be collected into groups and then to form a geological model. This is the same way defined in WMS that features group into layers and then to form a map. Also like the WMS's way, *sGDM* gets visualization parameters encoded in OGC Symbology Encoding (SE) specification [14], and has it bound with geological feature groups to define geological feature objects' appearance in a model. Of course, it is necessary that *sGDM* extends the existing SE standard from 2D to 3D to support 3D visualization. *sGDM* also benefits from a couple of other existing standards. Figure 1 and Table 1 show all the existing standards that contribute to *sGDM*.

*sGDM* makes itself be compatible to the already declared standards by reusing them. Furthermore, some coming standards, such as OGC discussing papers of Web 3D Service (W3DS) [15] and 3D-Symbology Encoding (SE-3D) [16], have also been studied to design *sGDM*. This makes sure that *sGDM* can be easily refined to work with these coming standards.

TABLE I.
EXISTING STANDARDS THAT *sGDM* RELIES ON

| Name | From | Verison |
|---|---|---|
| GeoSciML | IUGS: GeoSciML | 3.0 |
| GML | OGC: Geography Markup Language | 3.2.1 |
| SE | OGC: Symbology Encoding | 1.1.0 |
| SWE | OGC: Sensor Web Enablement (SWE) Common Data Model Encoding Standard | 2.0 |
| Filter Encoding | OGC: Filter Encoding | 1.1.0 |
| OM | OGC: Observations and Measurements | 2.0 |
| GMLCov | OGC: GML Coverages Application Schema | 1.0 |

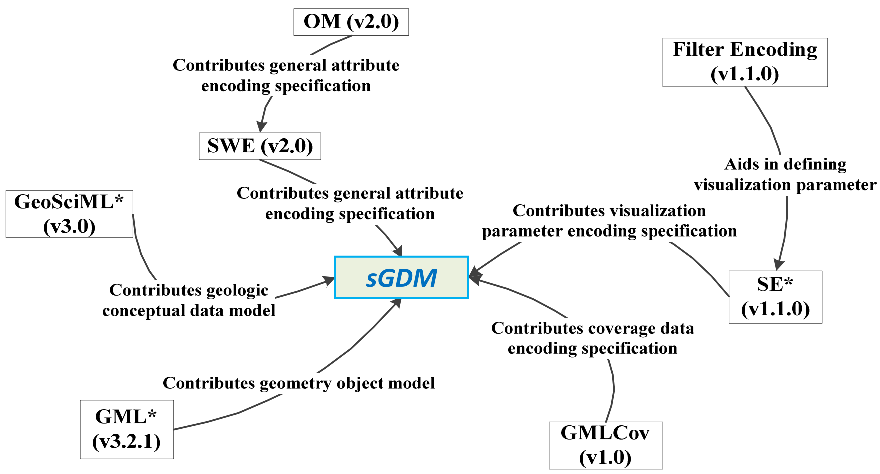


Figure 1. Contributions from existing standards to *sGDM* (*: standards that *sGDM* makes extensions to)

## A. *Conceptual Model of sGDM*

The conceptual architecture that geological features constitute geological models is depicted in Figure 2. From top to down, a modeling workspace may contain several geological models, while a geological model can classify its “cells”, geological feature objects, into several feature groups. Feature objects’ appearance may vary dependent on applications’ specification. It is reasonable to keep feature objects’ semantic data being loosely related to their visualization styles. In *sGDM*, a feature group can reference a visualization style as the default appearance configuration to its sub feature objects.

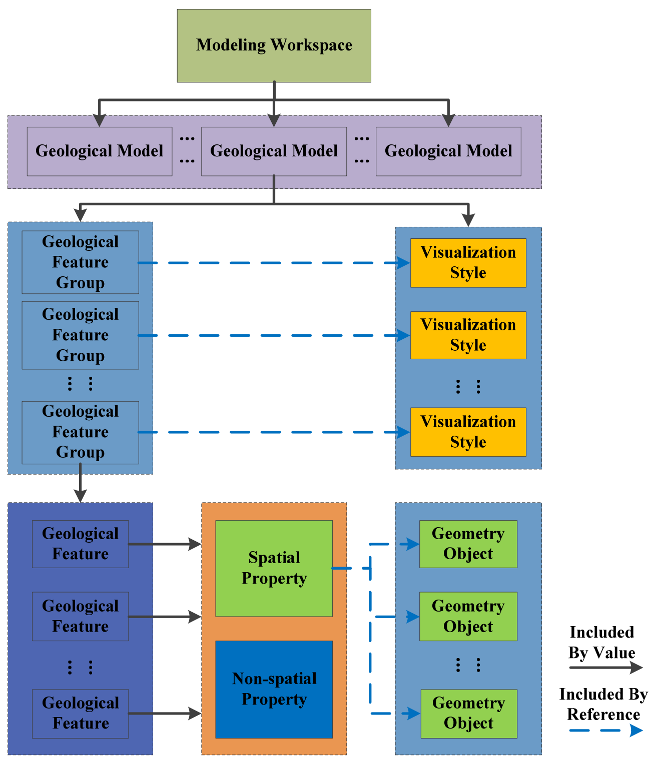


Figure 2. Geological model’s structure in *sGDM*

According to the conceptual architecture mentioned above, *sGDM* has its core classes defined as those shown in Figure 3. The abstract class gsml:GeologicFeature representing geological feature comes from GeoSciML. The class of sgdm:GeoFeatureGroup is the feature collection referring to the geological feature group show in Figure 2. And the class of sgdm:AbstractGeoMap represents the geological model concept in Figure 2. Here, a “map” refers to an entity that consists of groups of related geological features, but not only a classic geological map. *sGDM* also thinks a sgdm:AbstractGeoMap is really a geological model. And, sgdm:GeoWorkSpace means the modeling workspace in Figure 2.

GeoStyle in Figure 3 is the structure for storing visualization parameters. It encodes data in the way defined by OGC SE standard and the extension that *sGDM* has made to SE standard. This extension is mainly about parameters of light, material and texture to the point, line, and surface symbolizers given by SE.

GeoFeaturGroup borrows the structure of swe:DataRecord from OGC SWE standard to depict the schema of customized attribute fields bound to geological features in the group. Every field will have a unique name, and a declaration of its value type.

According to GeoSciML, a gsml:MappedFeature object will connect a gsml:GeologicFeature object to a geometry object which represents the geological feature’s spatial shape in a specified map context. *sGDM* extends this concept to let an object of class GeoMappedFeature inherited from class gsml:MappedFeature represent a geological feature’s occurrence in a general attribute space (spatial/non-spatial attribute space).

## B. *Geological Map*

*sGDM* uses an abstract concept “map” to represent geological models, which are constituted by a couple of related geological features. Figure 4 shows all specific “map” types that *sGDM* defines. A borehole (sgdm:Drill) is a geological map which is constrained to extending along the borehole’s curve trace. Conventional section (sgdm:Section) and plane geological map (sgdm:PlaneMap) are typical geological maps. And it is also straightforward to recognize a 3D geological model (sgdm:Map3D) as a 3D map. Even though samplings (sgdm:Sample) can be recognized as a geological map defined on all the sampling positions. This is in conformity with what "map" means in OGC Abstract Specification, too [17].

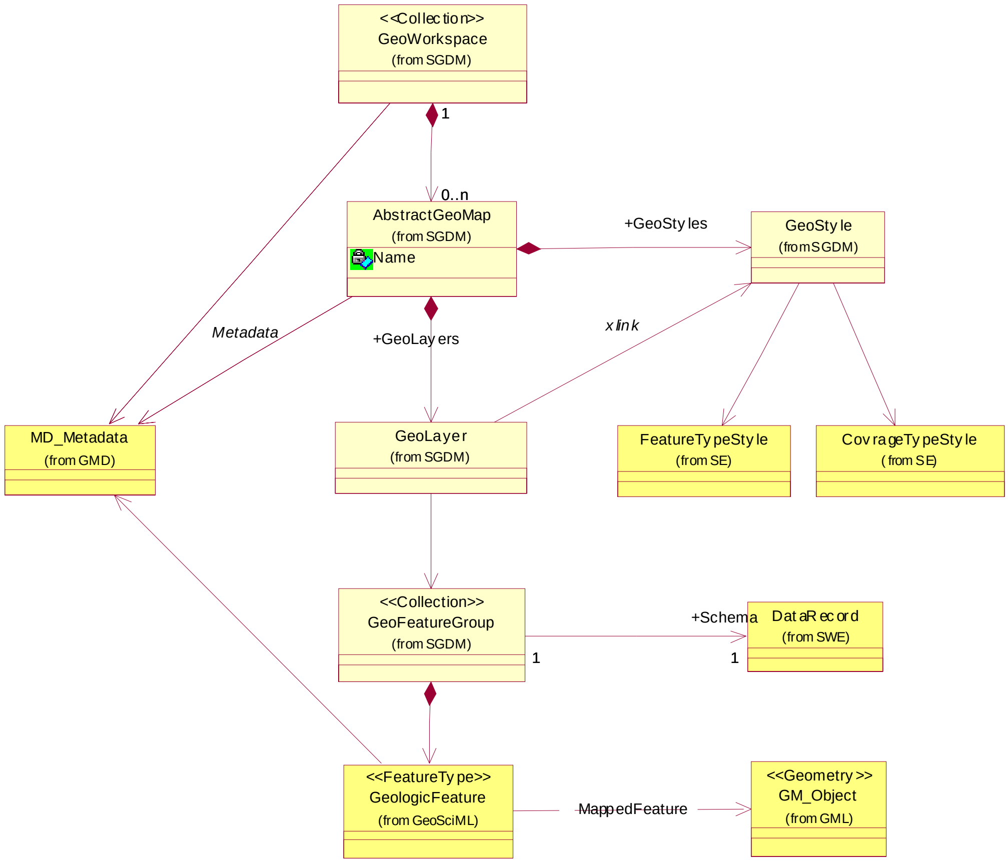


Figure 3. Core classes of *sGDM*

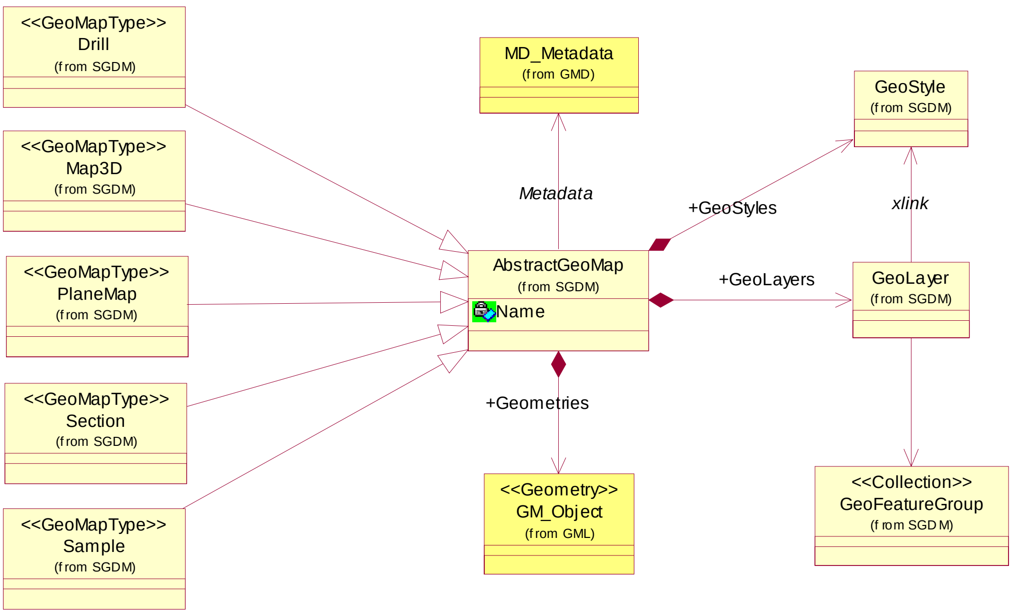


Figure 4. Classes from *sGDM* 's geological map module

### *C. Geological Feature Group*

As shown in Figure 3, a geological feature group constitutes of three parts: geological feature objects in the group, schema of the customized attribute fields, and a reference to the default visualization style definition of its feature members. These three components are stated in the following three sections respectively.

### *D. Geological Feature Object*

GeoSciML have defined various classes to capture geological concepts and objects. These classes are all rooted from class gsml:GeologicFeature. A gsml:GeologicFeature object can tell the observation method and purpose that people adopt to extract its value. A gsml:GeologicFeatureRelation object can be used to connect two gsml:GeologicFeature objects and log their relationship with a standard term. And a gsml:MappedFeature represents the related gsml:GeologicFeature object's occurrence in a specified map context. A gsml:GeologicFeature object may have several gsml:MappedFeature values, since it can show up in several maps.

By taking spatial attribute or non-spatial attribute as a general attribute field, *sGDM* recognizes feature's any attribute value as one of its "occurrence" in the corresponding attribute space. It is straightforward that the occurrence is dependent on the observation or measurement conditions. As in the task of estimating mineral resource reserve, it is dependent on resource rank definition that estimated reserve varies, and also mineral body's valid spatial distribution varies. Sometimes, it is the spatial shape that becomes a factor of influencing object's attribute value. For instance, the common attribute values of a gml:Coverage feature tightly rely on the spatial shape defined in the gml:Grid member. Although gsml:MappedFeature has a gsml:samplingFrame member to state some kind of observation conditions, it cannot deal with more complicated conditions, such as time variable attribute, in an well-defined manner. It may require another elegant solution based on a more generalized GIS data model.

*sGDM*'s extension to GeoSciML talked above is implemented in a class sgdm:GeoMappedFeature inherited from gsml:MappedFeature. In the derived class, a name referring to the corresponding attribute field can be assigned. And the observation value can be saved in another member which is an object of class om:Result from OGC OM standard.

### *E. General Attribute*

It is conventional to have the customized attribute fields' schema defined in sgdm:GeoFeatureGroup, just as the schema definition in an ArcGIS FeatureClass object. sgdm:GeoFeatureGroup is a more general feature group than an ArcGIS FeatureClass. Features in the ArcGIS FeatureClass share the same feature type and geometry type, while those in a sgdm:GeoFeatureGroup only share a customized attribute table schema. And *sGDM* borrows the swe:DataRecord structure from OGC SWE standard to record the schema. As stated in SWE, a swe:DataRecord object can be used as a data container or a data descriptor [18]. So, in *sGDM*, it works as a data descriptor. It should be noticed that SWE has not declared a data type which accept a geometry object as its value. It is lucky that gsml:MappedFeature has defined a separate member (gsml:shape) for hooking a geometry object. By this way, *sGDM* can deal spatial attribute as a special attribute field by assigning its value in the designated member, although this is not an elegant manner.

OGC GML standard has already offered a full model for geometry objects [6]. *sGDM* reuses this well-defined model, and also defines two new structures to meet some real projects' need.

### *F. Visualization Style*

*sGDM* encodes 3D visualization parameters in the way that OGC WMS and SLD do. So, OGC SE standard plays an important role in this project. However, the declared SE standard is only 2D enabled. *sGDM* has studied CityGML, X3D, and the OGC discussing papers (W3DS and SE-3D) to extend the SE standard, and get the visualization style module designed. Classes from this module are shown in Figure 5.

Class sgdm:GeoStyle is much like the class sld:UserStyle defined in OGC SLD standard [19]. Since SLD works too closely with WMS, *sGDM* has not directly reused its definition, but defined a similar class. A SLD:UserStyle object can easily be constructed based on a sgdm:GeoStyle object's value.

The key content of a sgdm:GeoStyle object, including se:FeatureStyle, se:CoverageStyle, se:Rule, se:Symbolizer etc., comes from the OGC SE standard. To meet 3D visualization application's requirements, *sGDM* extends se:PointSymbolizer and se:LineSymbolizer by appending an additional sgdm:X3DMaterial object to offer 3D light, material parameters. A new class sgdm:GeoSurfaceSymbolizer is designed to define 3D surface's (mainly as Triangulated Irregular Network, TIN) visualization parameters. For a 3D surface, its front or back face's visualization parameters, light, material, and texture, can be assigned respectively. Furthermore, if a surface consists of surface facets, typically a TIN, then its vertices' and frame lines' visualization parameters can also be assigned respectively. The class sgdm:X3DMaterial is designed based on X3D, and class sgdm:AbstractTexture together with its derived classes are designed based on corresponding classes in CityGML.

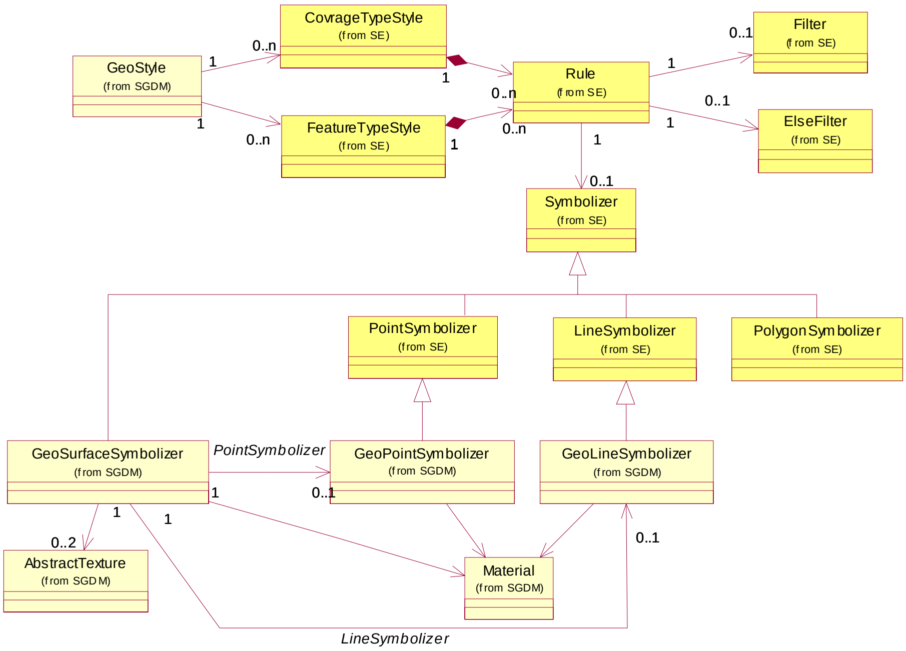


Figure 5. Classes from *sGDM*'s visualization style module

## *G. Relationship between Geological Features*

There is a rich set of relationships between geological features. Some of them are related to domain knowledge, such as an igneous unit intrudes a sedimentary unit. And some of them can be spatial topology relationships. In GeoSciML, class gsml:GeologicFeatureRelation is designed to hold the relationship between two gsml:GeologicFeature objects. Both of the sematic of the relationship and the roles of the two related features can be stated by the gsml:GeologicFeatureRelation object. And the key task is to edit a public dictionary of standardized domain terms. Such a dictionary defined by CGI and used by GeoSciML can also be used by *sGDM*.

# IV. Application

For common 3D geological data processing projects a large amount of geodata need to be stored and served to different users for a long time. Therefore, it is essential to have an efficient and reliable data management.

To evaluate the *sGDM*, this section presents successively a high level prototype architecture prototype for the integrated, XML-based storage and exchange of 3D geological data, which uses *sGDM* illustrated in Fig. 6.

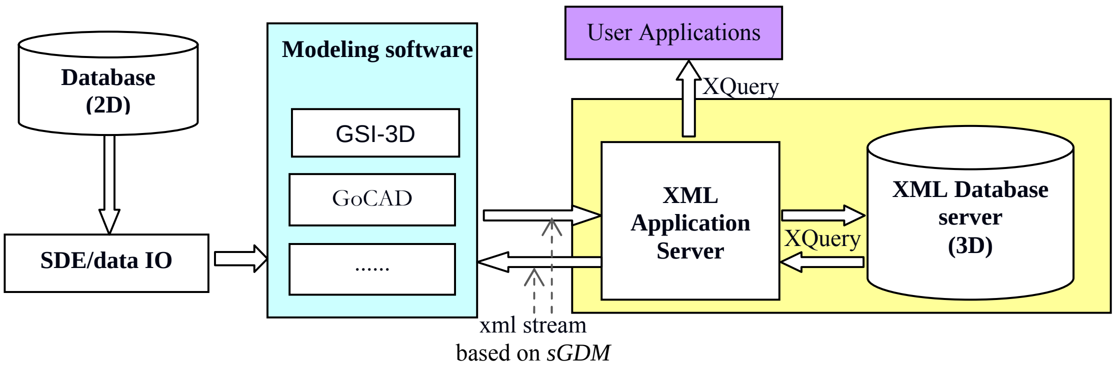


Figure 6. The prototype architecture for XML-based storage and exchange of 3D geological data

## *A. GML-based Data Management Architecture*

The rapid development of XML/GML technologies has opened up opportunities for GIS communities to design new (or complementary) geodata services, which enable geo-scientists to easily manage geoinformation in a form that supports their domain knowledge.XML processors are employed to support the processing of geospatial information encoded in GML, and the performance of using XML/GML-native technologies to manipulate large GML documents is proved as well as a DB-driven method [20].

With the prototype, geological modeling software is instantiated and can interoperate with each other and geological originations governing geodata can provide data services. Therefore, the prototype architecture is suggested which Features:

(1) A client-server architecture, where geomodelling applications act as clients of a database server for geomodels and primary observation data. The prototype architecture depicts a communication process, which takes place between two geomodelling softwares. They exchange information through a communication channel using *sGDM*-based XML streams. In this architecture, all geomodelling softwares have an identical internal structure and operate in the same manner. And, this architecture is not limited to only two softwares but can be expanded to multiple softwares interacting in pairs.

(2) XML-based database storage and management, including 3D spatial data services for different users. The coupling of a professional 3D geomodelling software and a database management system in a componentoriented framework can provide a 3D geoscience information system offering comprehensive spatial and geological query possibilities. In order to realize the proposed system, the extensible standard XML query language (XQuery) has been extended by 3D spatial operators. The spatial query functions can be included in an XQuery expression and combined with other spatial and nonspatial terms. The return value of an XQuery is always a valid XML document which can be also coded in *sGDM* complementary format. The application server acts as an efficient middle-ware component which obtains the data of a project from the database and sends the computed result set to the user application.

### *B. Implementation*

The application server is an integrated platform for providing 3D geodata I/O interfaces, query and analysis functionality. The application server has been implemented in C++ in a generic, standards-conformable way and can be used with various XML-supporting databases and applications, including geomodelling systems and other user applications, like iInternet browsers. Figure 7 shows a snippet of the XML codes that encodes an example of 3D geological model, the model extracted from the data exchange files that is encoded in *sGDM*-defined format. Figure 8 and Figure 9 show the example model visualized in desktop–based and internetbrowser–based user applications, respectively.

```
▼<gmml:Map3D xmlns:gmml="http://www.cgs.gov.cn/GMML" xmlns="http://www.cgs.gov.cn/GM
 xmlns:gsml="http://xmlns.geosciml.org/GeoSciML-Core/3.0" xmlns:gsmlst="http://xmlns
 xsi:schemaLocation="http://www.cgs.gov.cn/GMML file:/E:/GMML/docs/schema/GeoMap.xsd
   <Name>Model-1</Name>
  ▶<Metadata>...</Metadata>
   <Geometries></Geometries>
  ▼<GeoStyles>
    ▶<GeoStyle gml:id="Model-1-Marks-Style">...</GeoStyle>
    ▼<GeoStyle gml:id="Model-1-Faults-Style">
       <gml:name>Model-1-Faults-Style</gml:name>
      ▼<se:FeatureTypeStyle>
        ▼<se:Rule>
          ▼<GeoSurfaceSymbolizer>
            ▶<Front>...</Front>
             <Back></Back>
           </GeoSurfaceSymbolizer>
         </se:Rule>
       </se:FeatureTypeStyle>
     </GeoStyle>
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   </GeoStyles>
  ▼<GeoLayers>
    ▼<GeoLayer>
      ▼<GeoFeatureGroup gml:id="Model-1-Stratums">
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        ▼<Schema>
          ▼<swe:field name="Stratigraphical_Name">
             <swe:Text></swe:Text>
           </swe:field>
           <swe:field name="Shape"></swe:field>
         </Schema>
        ▼<Members>
          ▼<Member>
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               <gsml:observationMethod/>
               <gsml:purpose/>
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               <gsmlgu:exposureColor/>
               <gsmlgu:outcropCharacter/>
               <gsmlgu:rank/>
               <gsmlgu:unitThickness/>
               <gsmlgu:composition/>
               <gsmlgu:metamorphicCharacter/>
               <gsmlgu:part/>
               <gsmlgu:physicalProperty/>
               <gsmlgu:alterationCharacter/>
               <gsmlgu:bedding/>
               <gsmlgu:geochemistry/>
               <gsml:classifier/>
               <gsml:metadata/>
             </gsmlgu:GeologicUnit>
           </Member>
         </Members>
       </GeoFeatureGroup>
       <GeoStyle xlink:type="simple" xlink:href="#Model-1-Marks-Style"/>
     </GeoLayer>
   </GeoLayers>
 </gmml:Map3D>
```

Figure 7. XML code snippet of an encoded 3D geological model

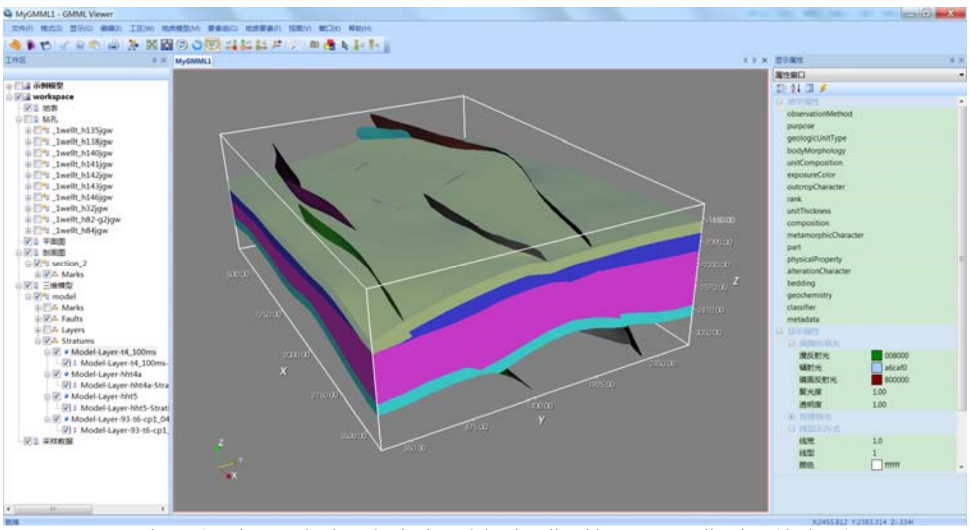

Figure 8. The standard geological models visualized in a user application (desktop)

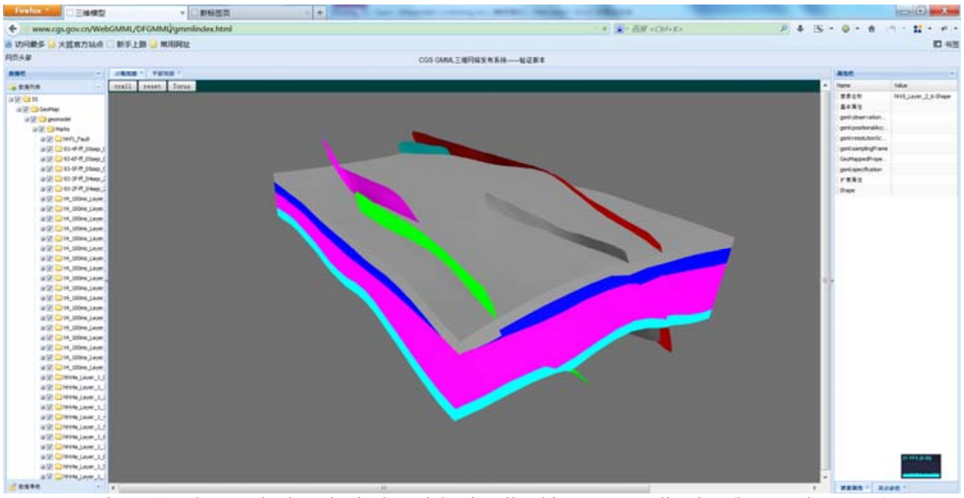

Figure 9. The standard geological models visualized in a user application (internet browsers)

## V. CONCLUSION AND FUTURE WORK

In this paper, we proposed a standard-based model, called *sGDM*, for the exchange of spatial and non-spatial properties of 3D geological data and presented a high level prototype architecture prototype for the integrated, XML-based storage and exchange of 3D geological data. In this architecture, user and data provider software maintain an identical internal data structure and exchange information through a communication channel using *sGDM*-based XML streams.

And *sGDM* is now a part of the ongoing research task of geological model markup language (GMML) which is planned in the China Geological Survey (CGS) special project of Geological Mineral Resource Investigation and Estimation. CGS will first utilize it as a candidate 3D geological model exchange format within CGS's applications. We will keep on refining *sGDM* based on these coming application experiences.

Although we consider the model and the experimental prototype to be successful, a number of issues still need to be addressed, notably in (1) the development of more rigorous ontologies, (2) the extraction of intrinsic and extrinsic properties from natural language definitions of geological data, attributes, attribute values, etc., (3) the integration of application, domain, and global ontologies and their interactions. Finally, we believe that this research takes a step forward in the achievement of the data sharing of 3D geological data.

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